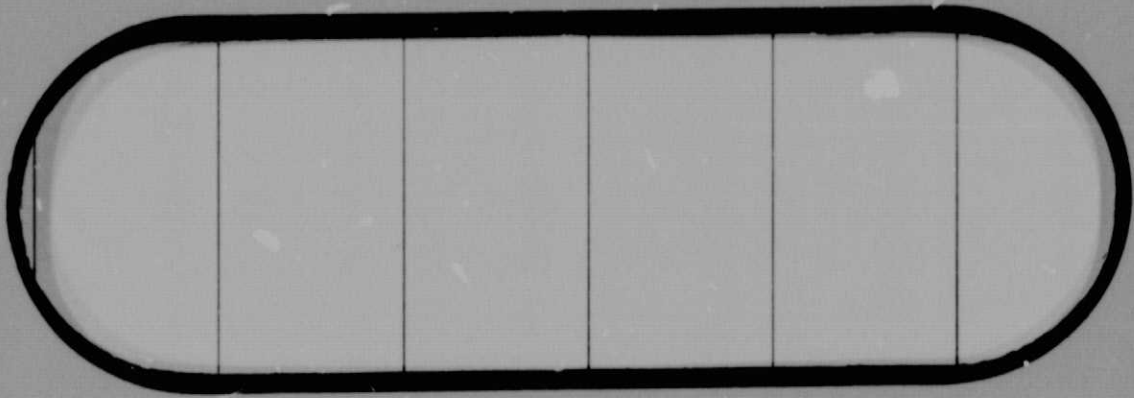


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(NASA-CR-137530) BRAKE CONTROL SYSTEM
MODIFICATION, AUGMENTOR WING JET STOL
RESEARCH AIRPLANE (AWJSRA) (Boeing
Commerical Airplane Co., Renton, Wash.)
78 p HC \$7.00

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THE **BOEING** COMPANY
COMMERCIAL AIRPLANE DIVISION
RENTON, WASHINGTON

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TITLE: BRAKE CONTROL SYSTEM MODIFICATION - AUGMENTOR
WING JET STOL RESEARCH AIRPLANE (AWJERA) CONTRACT NAS2-7641

MODEL MOD C-8A

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1.0

INTRODUCTION

Contract NAS2-7641 between the Boeing Company and NASA Ames Research Center was modified in November 1973 to include Task 4, a program to improve the braking system on the Augmentor Wing Jet STOL Research Airplane, ("Buffalo Airplane"). Task 4 specified that Boeing would provide and demonstrate an anti-skid system which would prevent tire damage, and also evaluate the existing manual braking system and correct any inherent problems. Task 4 also specified that NASA would install the anti-skid system and make any changes required to improve the manual braking system.

During January 1974 the Buffalo Airplane was equipped with a Hydro-Aire MK II anti-skid system and other braking system improvements. During the same month, the airplane was successfully demonstrated to NASA personnel in a series of taxi and flight test at Moffett Field, California.

This document is the final report on the work which was done by the Boeing Company under the aforementioned contract.



2.0

SUMMARY

The braking system which existed on the Buffalo airplane prior to improvements described in this report, was a stock de Havilland system except for tires, wheels, and brakes which were replaced in early 1972 with those used on the Boeing 727 airplane nose gear. The higher heat sink of the 727 brake was required for the many closely spaced landings which the airplane was expected to make.

Two deficiencies were determined during evaluation of the above manual braking system. Pressure control with the existing metering valves was erratic and the stock 727 brake had much more torque capability than required for the 45,000 lb. Buffalo airplane. The primary modification which was made to correct the erratic pressure control problem was to replace the existing Bendix metering valves with the same metering valves as used on the 727 airplane. The primary modifications which were made to correct the excessive brake torque problem were to deboost the hydraulic brake pressure and also reduce the torque capability of the brake.

Under Task 4 a Hydro-Aire MK II anti-skid system, similar to the one used on the 727 airplane was selected for the Buffalo airplane. All brake system pressure lines and all return lines were modified to allow unrestricted high transient flows which occur during anti-skid operation. All hydraulic components were converted for use of MIL-H-5606 red oil and BMS 3-11V fine resistant fluid.

The new anti-skid system and braking system modifications described above were evaluated at the Boeing brake and anti-skid simulation facility. A special analog computer/hardware simulator was constructed for this purpose. As a result of simulator testing, the anti-skid control cards were tuned to provide landing gear stability. Also, additional modifications were made to the hydraulic system to provide improved manual braking. The anti-skid system and all other braking system improvements were installed on the Buffalo airplane by NASA.

The new braking and anti-skid system was demonstrated in a series of medium effort and maximum effort taxi stops, and maximum effort landing stops. There were no flat spotted or blown tires. Undesirable yawing of the airplane occasionally occurred at lower speeds and was attributed to simultaneous release of both brakes on the same gear. This is a characteristic of airplanes such as the Buffalo which have widely spaced main landing gear and a low polar mass moment of inertia about the yaw axis. Additional tuning of the anti-skid system would partially but not completely correct this problem.



3.0 AIRPLANE DESCRIPTION

3.1 GENERAL FEATURES

The AWJSRA is a 45,000 pound, 50 psf wing loading, turbofan powered airplane designed for research in the STOL terminal flight regime. The airplane is derived from a deHavilland C-8A "Buffalo" airframe. Augmentor wing jet flaps, blown and drooped ailerons and leading edge slats have been added to produce high lift capability for STOL research. Wing span has been shortened to increase loading. Two Rolls Royce Spey 8013F jet engines provide blowing air to the flaps and ailerons via ducts as well as direct hot thrust through vectorable Pegasus nozzles. A three view of the airplane is shown in Figure 1.

The AWJSRA has two independent, equal capacity 3000 psi hydraulic systems using MIL-H-5606 fluid. The electrical system is powered by two engine driven 115/200 volt, three phase, 400 Hz brushless generators that are connected to normally isolated left and right a.c. busses and through rectifiers to the left and right d.c. busses. A 24 volt battery is connected to the left d.c. bus.

The airplane, as modified for NASA from the deHavilland Buffalo, has four 727 nose wheels and brakes, two on each main gear. The deHavilland brake control system included Bendix metering valve/pressure reducers, actuated from the paired brake pedals through links and bellcranks. The metering valves reduce 3000 psi system pressure to a range from 0 to about 1200 psi, depending on the depression of the valve stem. The hydraulic lines from the valves to the brakes (including the hoses on the struts) were 1/4 inch and approximately 35 feet long.



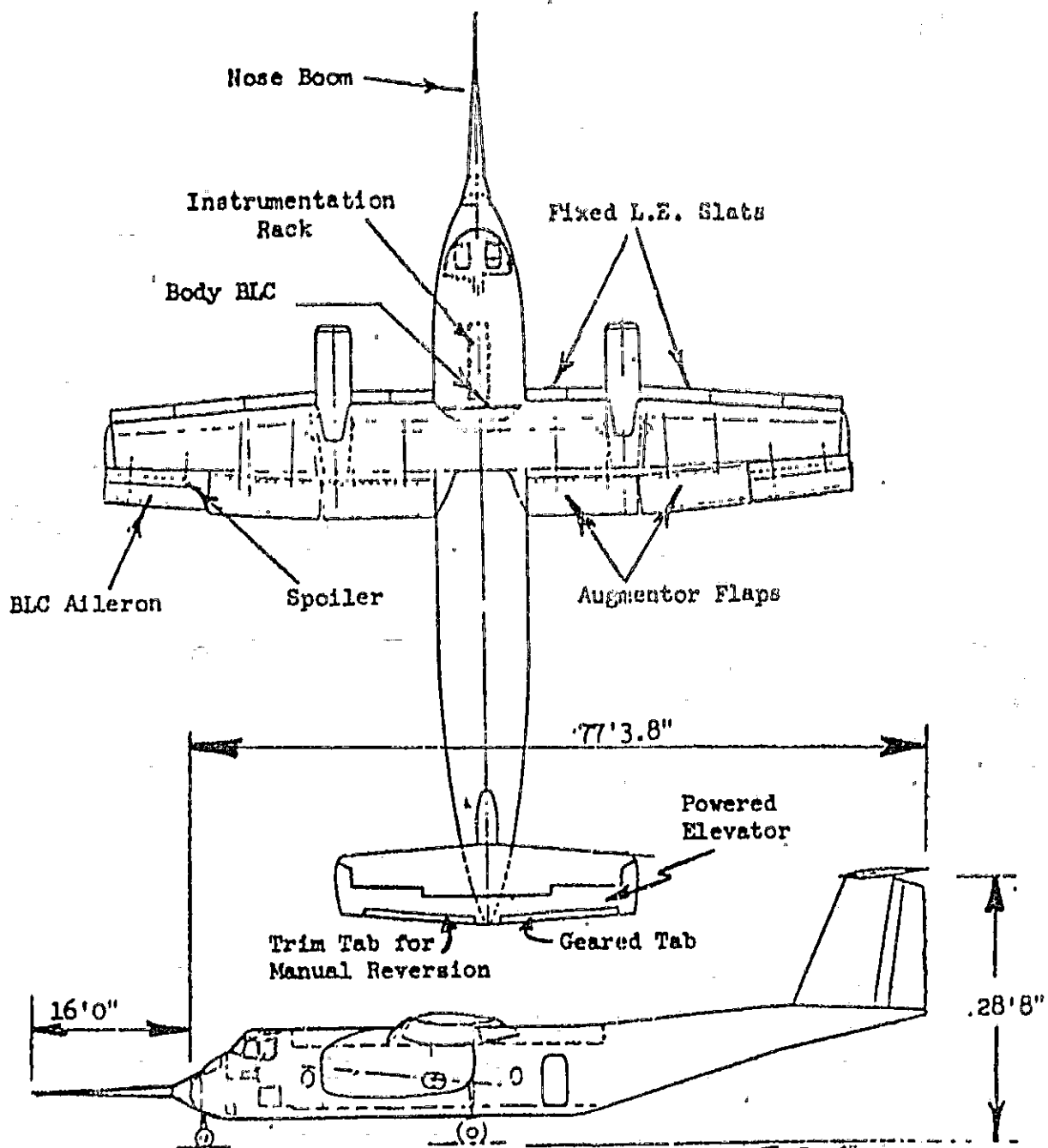
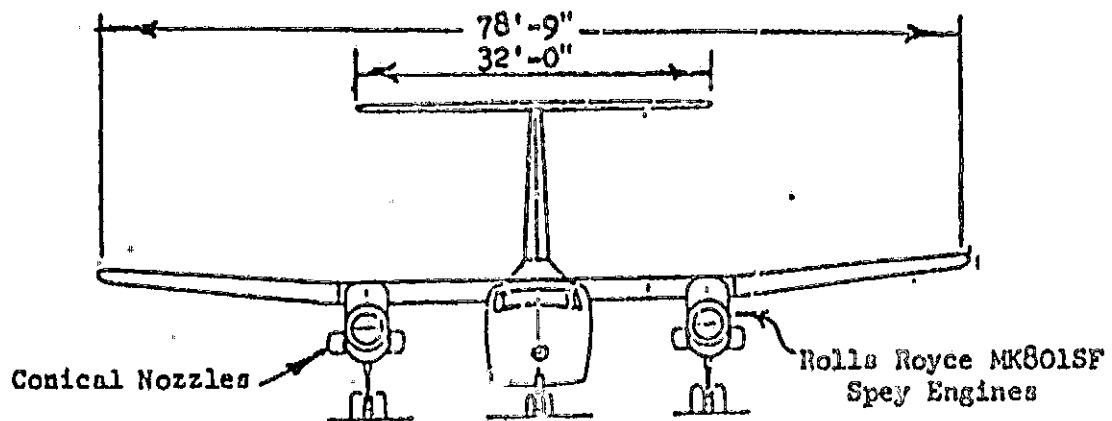


FIG. 1

The 727 nose wheel brakes had been selected on the basis of their heat sink capacity, anticipating the high frequency, short flight usage of the airplane. During the Task 4 study it was found that off-the-shelf 727 nose brakes have much more installed torque than required for the Buffalo airplane. To correct this problem the brakes were modified to reduce the installed torque.

3.2 BRAKING CONTROL PROBLEMS

There were two basic problems with the braking system. Smooth modulation of brake torque during application or release was not possible, and it was too easy to apply excessive brake pressure causing flat spotting or blowing of tires.

3.3 REMEDIAL MODIFICATIONS

3.3.1 Enlargement of Hydraulic Lines

The 1/4 inch diameter brake lines and fittings were replaced with 3/8 inch diameter for pressure lines and 1/2 inch diameter for return up to the anti-skid valves. From that point to the brakes, pressure and return occur in the same lines and those lines were made 3/8 diameter. The modification to the brake hydraulics plumbing is shown by the revision to drawing number 65-83434, sheet 6, -6, Brake Control System Modification (Buffalo C-8A Mod.).



3.3.2 Incorporation of Anti-Skid Control

These same drawings show the changes required to incorporate anti-skid control into the braking system. Basically this involved interposing the anti-skid valves between the metering valves and the brakes, so that they reduce brake pressure when necessary to prevent undesired skidding. It was also necessary to interpose pressure reducing deboost valves, because the anti-skid valves were designed for use in a 3000 psi system and the brakes were designed for 1150 psi.

The anti-skid valve selected was a Hydro-Aire part number 39-045 and the two dual valves were modified by Hydro-Aire to accept MIL-H-5606 hydraulic fluid. The deboost valves are a Berten part, Boeing drawing number 10-60574-7, modified by seal change to accept MIL-H-5606 fluid.

The anti-skid control also required the installation of wheel speed transducers, an anti-skid control computer, and a control panel along with modification of the electrical system. The wheel speed transducers are Hydro-Aire wheel speed transducers, Boeing part number 10-60578-2.

It is essential, in the installation of such transducers that no cyclical signal variations be introduced by the coupling between the wheel and transducer and that no "noise" be generated by looseness or rubbing. To meet this requirement a special coupling system was designed with special attention to accurately centering the transducer in the axle, accurately centering the driving member in the wheel hub, and designing a coupling arm able to accommodate angular and linear misalignments between them without converting them to angular rotation variations.

The anti-skid control computer (or box) selection was a Hydro-Aire unit, part number 42-527D, modified by Hydro-Aire to operate with 32 inch O.D. tires. As described in Section 4.0 the control box was "tuned" by simulator testing at Boeing. The tuning changes will be incorporated into the design by Hydro-Aire. The control box was installed by NASA in a standard electronic rack tray, Boeing number 65-22501-107 using a Fork Assembly (Camloc 27L1-2) for retaining it.

The control panel is a modified 727 airplane control panel, Boeing part number 69-61197-5. Modification consisted of removing a RC lag circuit which is normally tied to the locked wheel arming circuit. The RC circuit is of use only on very slick runways and was not required for the Buffalo airplane. Removal was in the interest of simplification.

The control panel, as delivered to NASA, was too large for installation in the previously selected space. NASA was subsequently successful in installing the panel after further modification.

Modification of the electrical system is shown on drawing number 65-83552 and on advanced drawing change notice #11 of drawing 65-83008. These modifications provided power to the anti-skid components, and the wiring of the anti-skid system including cockpit displays. The ADCN covered the circuit breakers for the anti-skid system.

3.3.3 Braking System Hardware Changes

It was necessary to replace the deHavilland (Bendix Pacific Division) brake metering valves with units operating to the 3000 psi required by the anti-skid system. The valve selected was a Sargent Engineering Corporation valve, manufactured to Boeing Specification 10-3205-1 and modified to part number 65-83551-60 by resealing for use with MIL-H-5606 fluid.

The valve replacement required modification of the brake linkage to provide the extra stroke required at the valve without increasing brake pedal deflection and to keep brake pedal pressure in the desired range. Since the feedback force at the new valve was less than that of the Bendix valve and the stroke was greater, one linkage change satisfied both requirements. The idler links were replaced with links giving the pedals less mechanical advantage. The new links are right and left hand parts, assembly numbers 65-83551-7 and -8 respectively.

The valve replacement also required an adaptation of the deHavilland (Bendix) valve actuation lever assembly to the Boeing valve. In the Bendix assembly the arcuate travel of the lever was converted to the rectilinear motion of the valve stem by a short spherical ended rod carried between conical sockets on the lever assembly and the valve stem. An attempt was made to use this technique on the Boeing valve. However mechanical function of the valve on the simulator was sticky and erratic, probably because of the extra travel (and angular displacement of the rod) and the sensitivity of the Boeing valve to side loads on the stem. The



Bendix valve gave smooth performance on the simulator but was never used with the "rod and sockets" actuation. There is reason to believe that some of the erratic brake performance of the unmodified brake system could have been caused by this mechanical arrangement.

The present mechanism, using a "crosshead" type slider between the arcuate motion at the lever and the rectilinear motion of the valve relieved the valve of all side loads and provided satisfactory performance.

Also the Bendix valve contained a return spring which was strong enough to return the linkage and pedals to the brakes off position when foot pressure was relieved. The Boeing valve relied on hydraulic force based on system reservoir pressure. This force was marginal at best, possibly permitting brake actuation by inertial forces on the pedals, so return springs were installed between the upper pivots of the metering valve levers and nearby structure.

In the original system the right hand brake pedal controlled the right hand pair of brakes and the left hand pedal the left hand pair. In the modified system it was decided that the anti-skid system should provide "individual wheel control". This necessitated installing an additional brake line down each strut and replacement of the existing shuttle valves with a pair, per strut, of 65-83551-63 shuttle valves, which are Adel 71998 valves resealed for use with MIL-H-5606 fluid. The individual wheel control was chosen because it decreases chances of loss of all braking on one side due to any single failure.

4.0

LABORATORY TESTING

The purpose of laboratory testing was to custom tune the anti-skid system to the Buffalo airplane and to correct manual braking system incompatibilities. . Development of components was not a problem, since most were proven off-the-shelf items. A simulator was constructed at Boeing's Developmental Center especially for this purpose. The simulator is comprised of both actual hardware and an analog computer. The hardware is essentially a duplicate of the hydraulic braking system found in the airplane except only one brake line and brake was used. The analog computer was used to model both the airplane stopping motion and, of greater importance, the landing gear dynamics. Appendix A offers some data on the simulator.

Simulator testing was begun in November of 1973 and was completed the following month. It became evident during this test period that certain changes to both the hydraulic braking system and the anti-skid control circuit were necessary. Three changes were made to the hydraulic braking system, and two tuning changes were made to the anti-skid control circuit.

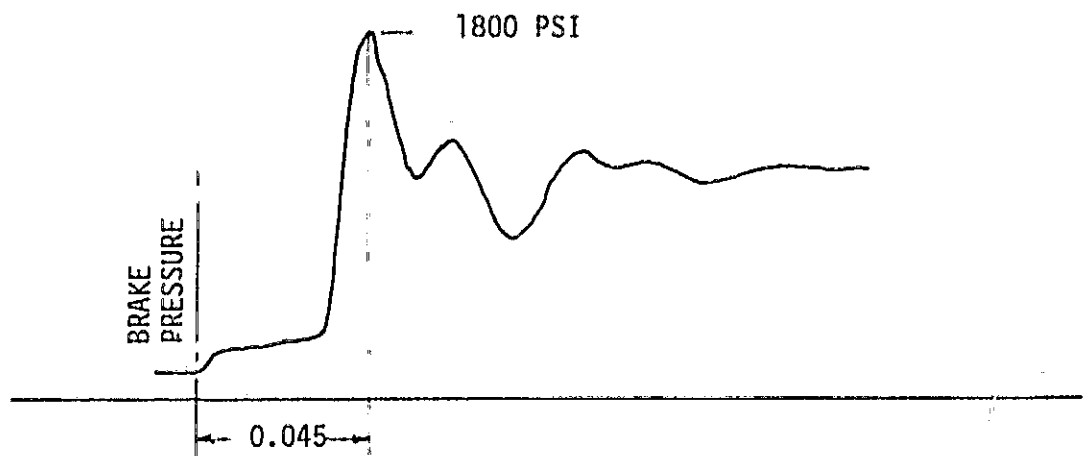
4.1

HYDRAULIC CHANGES

The three problems which necessitated changes to the hydraulic system were: -

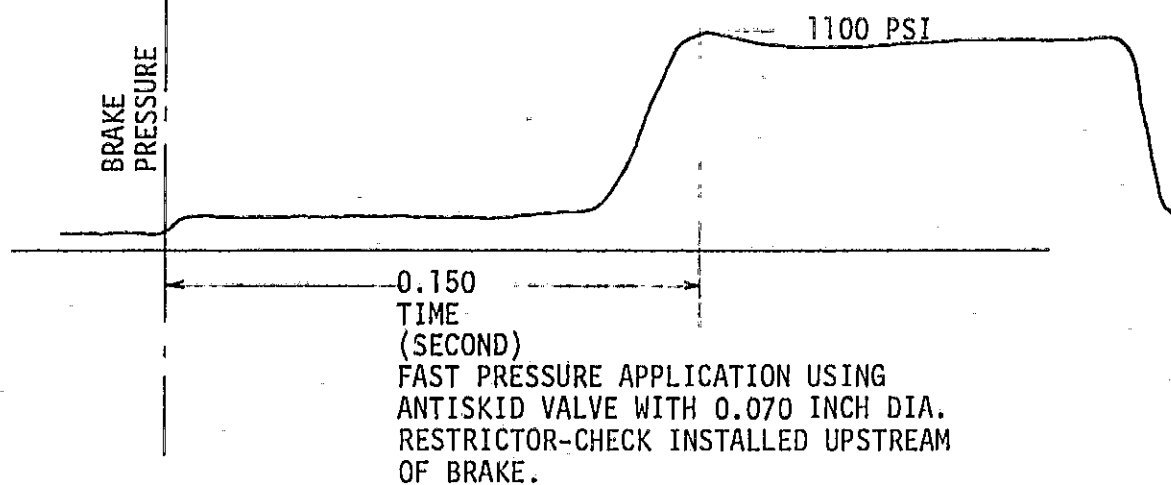
- (1) A tendency of the brake pressure to overshoot (or spike) during rapid application of brakes, see Figure 2.





FAST PRESSURE APPLICATION USING
ANTISKID VALVE AND NO ORIFICE

FIGURE 2



FAST PRESSURE APPLICATION USING
ANTISKID VALVE WITH 0.070 INCH DIA.
RESTRICTOR-CHECK INSTALLED UPSTREAM
OF BRAKE.

FIGURE 3

- (2) A brake pedal-to-metering valve linkage arrangement caused erratic pressure control.
- (3) Excessive torque capability of the brakes.

The pressure overshoot problem was corrected by installing a restrictor/check valve in each brake line just below the deboost valve. The flow rate of the oil into the brake was restricted by a 0.070 inch diameter orifice so that the normal compliance of the brakes was adequate to absorb the fluid momentum and not produce overshoot. Flow of oil from the brake was left unrestricted to allow rapid reduction of brake pressure during anti-skid operation. Brake fill and dump characteristics after the restrictor check valve was added are shown in Figure 3. If left uncorrected the consequences of brake pressure overshoot would have been evident in two ways. It would have been difficult for the pilot to initiate smooth manual braking since brake pressure and pedal force would not be proportional. The second detrimental effect was a tendency to produce an undesirable increase in fore and aft landing gear movement, which does aggravate gearwalk. Pressure overshoot during anti-skid activity is shown in Figures 4 and 5.

As mentioned previously, the metering valve input linkage problem was corrected by a redesigned linkage. The consequence of a sticky metering valve would again result in erratic braking control for the pilot since brake pressure and pedal force would not be proportional.



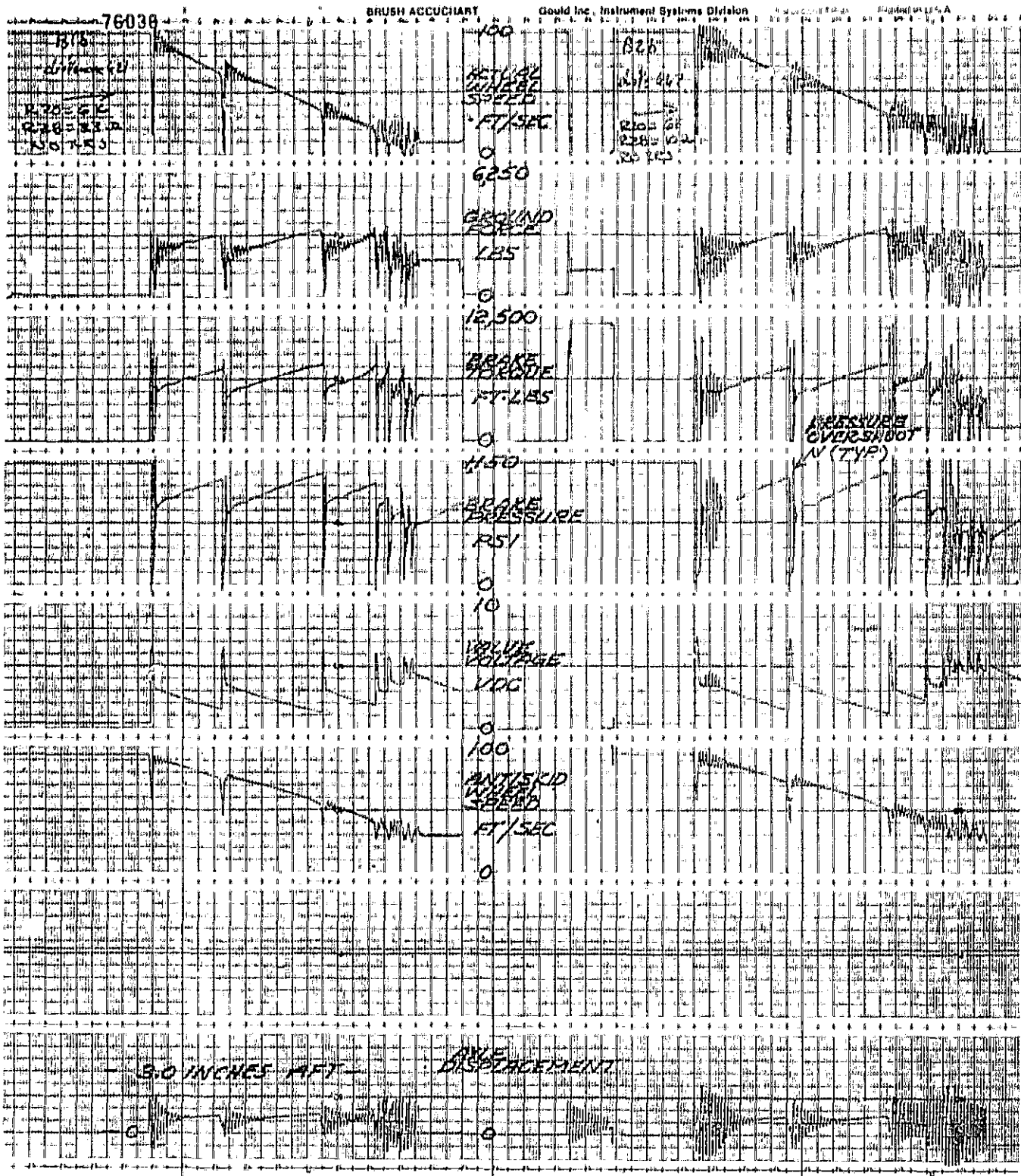


FIGURE 4

FIGURE 5

NOTES

1. The 727 nose brake with all eight pistons is shown as 100% torque.
2. The 727 nose brake with only six active pistons is shown as 75% torque.
3. The maximum and minimum landing weight cases are shown.

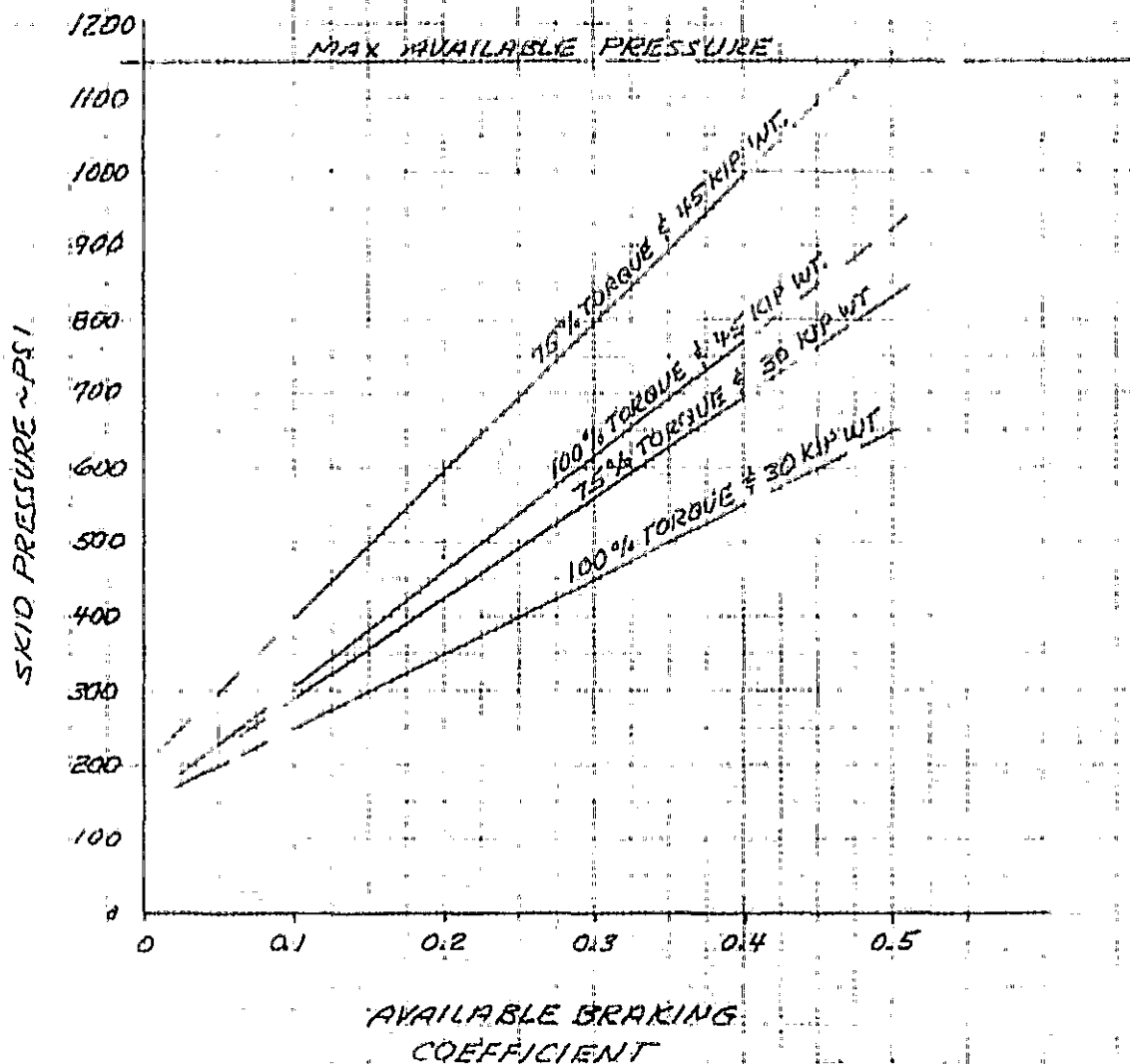


FIGURE 6

MATCHING OF BRAKE TORQUE
TO AIRPLANE WEIGHT AND
BRAKE PRESSURE

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The excessive brake torque problem was alleviated by deactivating two of the original eight hydraulic pistons in each brake piston housing. This resulted in approximately 25% reduction of brake torque. Figure 6 indicates the improvement resulting from this change. This change was made in an attempt to more closely match the brake torque to the weight of the airplane and available friction force of the tire-to-pavement interface. This resulted in brakes which are more easily controlled not only by the pilot, but also by the anti-skid system.

4.2 ANTI-SKID CIRCUIT CHANGES

The objective of tuning the anti-skid system was to provide tire protection over a wide range of runway friction conditions without causing instability of the main landing gear. To predict stability, the landing gear fore and aft natural frequency and damping should be known. The natural frequency was estimated at approximately 10 - 14 Hz, but the damping was completely unknown. Therefore, the gear was conservatively treated as lightly damped during all tuning. This approach resulted in:

- (1) Increasing the deceleration threshold to establish landing gear stability (resistor R20 was decreased in value from 13,000 to 4,700 Ω).
- (2) Increasing the valve current to extend operation of the system to lower runway friction coefficients (resistor R28 was decreased in value from 33.0 Ω to 4.7 Ω).

Figures 7, 8, 9, and 10 show the final tuning characteristics of a Buffalo anti-skid card at various braking coefficients.



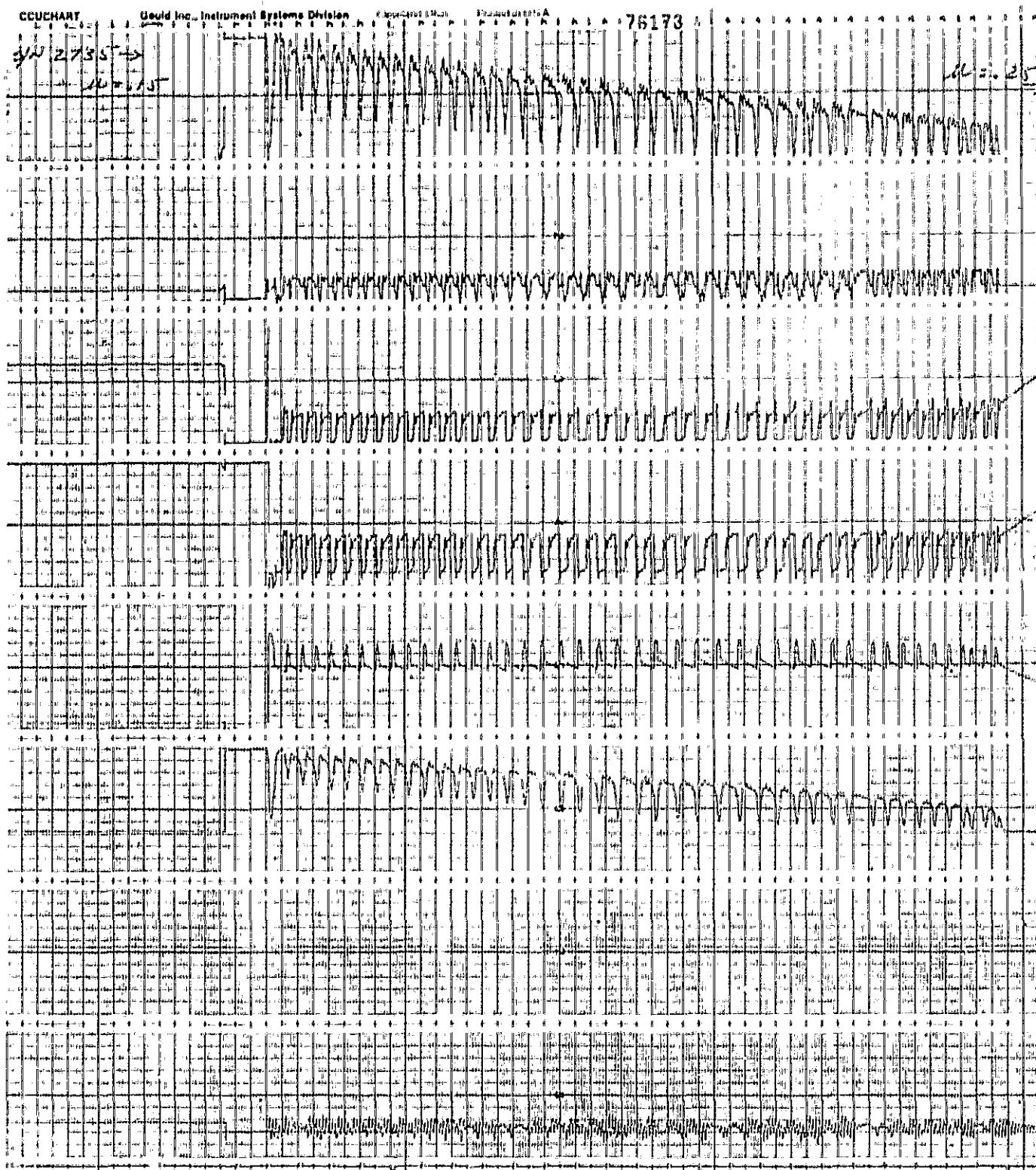
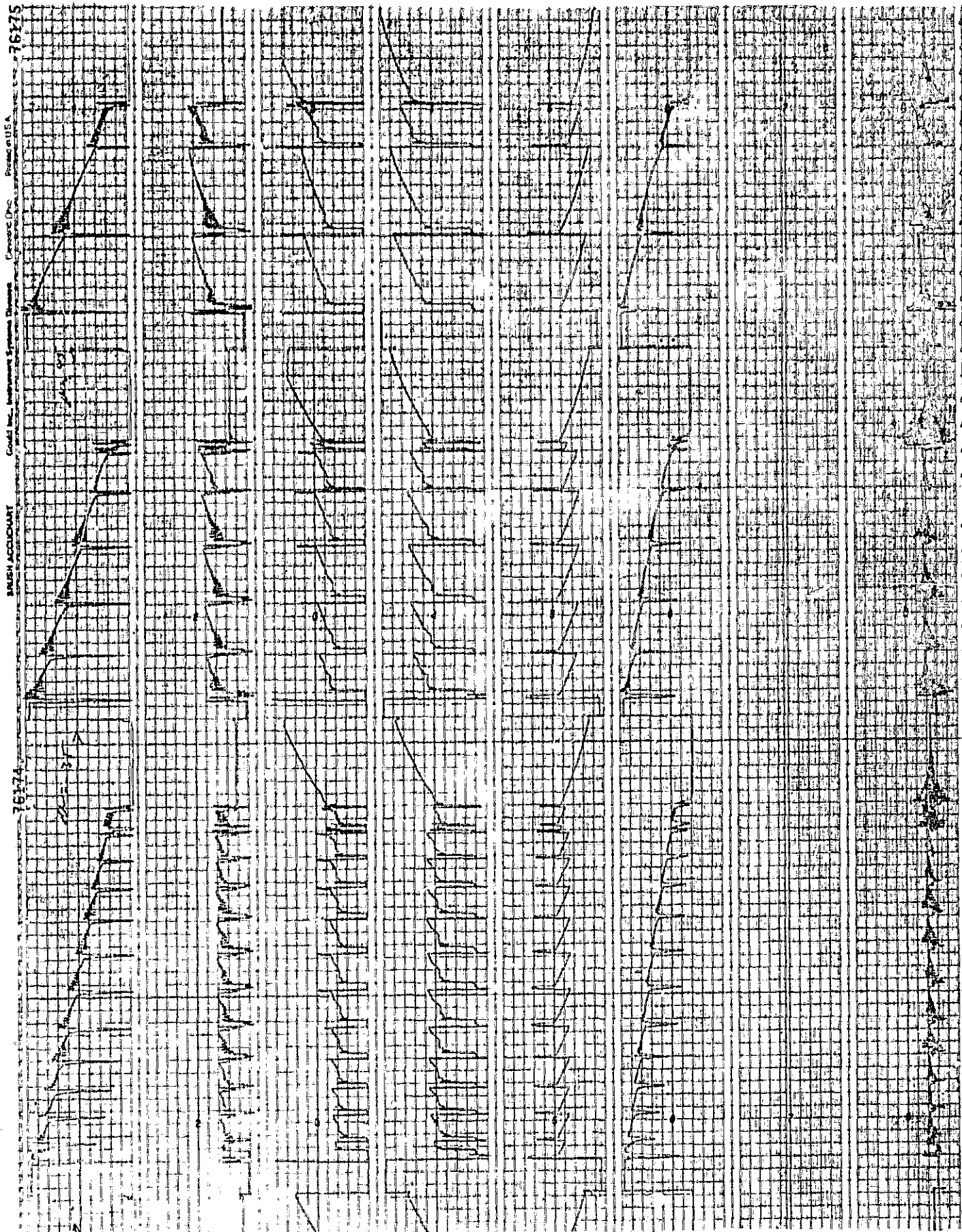


FIGURE 7

NOTE: See Figures 4 and 5 for trace identification and scales.



NOTE: See Figures 1 and 5 for trace identification and scales.

5.0

GROUND TESTING

As a first test of the system stops were made during taxi runs with the anti-skid off, to check the general function and to be sure that no unexpected releases of brake pressure occurred.

Then with the anti-skid system on, a series of operational aspects were assessed. Absence of dynamic coupling between the braking and gear structure was checked by rapid application and release of the right brakes at 10, 20, 30 and 40 knots. Stops were made at high taxi speeds, simulating landing rollouts, with various flap settings, and with lift dumped and not dumped.

Data recorded during these tests and the flight tests included:

- A. Wheels speeds (4)
- B. Anti-skid valve signals (4)
- C. Brake pressures (4)
- D. Brake metered pressure (one valve only)
- E. Drag strut load (1)
- F. Torque link load (1)
- G. Oleo extension (1)

An Electromagnetic Interference (EMI) test was conducted with no interference noted between the anti-skid system and the other electrical systems on the airplane.

No problems were noted except a tendency for the airplane to pull to the right during braking. The pull to the right was relieved by minor re-adjustment of the brake-pedal-to-metering valve linkage.



6.0

FLIGHT TESTING

Following successful completion of the ground testing, several landings were made, under various conditions. The first with normal approach, touchdown and braking to a full stop, checking for general operation and "locked wheel" protection. Subsequent conditions included stops with maximum braking effort, with and without lift dump, flaps at 65°, and brakes on speeds of 65 and 90 knots. No flat spotting or blown tires occurred during any stops.



7.0

CONCLUSIONS

The test results and pilot evaluation indicate that the program objectives have been achieved. The manual braking of the airplane exhibits acceptable sensitivity and the anti-skid system clearly protects against tire flat-spotting and blowouts which maintain excellent stopping capability.



APPENDIX ABUFFALO BRAKING SYSTEM SIMULATION DATAILLUSTRATIONS

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BOEING SKID CONTROL SIMULATOR

The simulator is an analog hardware system. The aircraft dynamics are simulated using analog computer equipment, but wherever possible, actual aircraft components are used instead of simulation. This simulation hardware system approach is used to provide a more accurate simulator, particularly in areas where non-linearities and complicated dynamics exist. An added benefit of reduced computer requirements is also realized.

Hardware

The hardware portion of the simulator includes all hydraulic system parts which can influence brake system performance. These include the pilot's metering valve, anti-skid valves, accumulators, pumps, supply and return lines, reservoir, and brakes. In this way the hydraulic system characteristics, including any non-linearities, are very accurately simulated.

Actual anti-skid control circuit cards are used in the simulator. Their use assures that no effects, no matter how minor, are neglected. The modern anti-skid control circuit is a complex system using tightly controlled tolerances. Its overall function is affected by the many feedback loops, non-linearities, and characteristics of the components used. Unless these components are reproduced precisely, the usefulness of the results can be seriously jeopardized.



Computer Simulation

The computer simulation consists of six inter-related elements:

1. Airplane Dynamics
2. Strut Dynamics
3. Truck Dynamics (not required for the AWJSR airplane)
4. Tire and Wheel Dynamics
5. Brake Torque Dynamics
6. Tire to Ground Force

The relationships and interactions between these elements are shown in the simulator block diagram Figures 1A and 2A.

A three degree of freedom airplane model is used to account for the vertical, forward (along the runway), and the rotational (pitching) movement of the airplane. The effects of the aerodynamic forces, the engine thrust, and the brake forces are included.

The simulation of the strut is a very important aspect of the simulator. A one degree of freedom system was used for the Buffalo airplane to account for the fore and aft deflection of the strut. The effects of the strut motion on the ground force, airplane dynamics and measured wheel velocity are also included.

The key elements in any skid control simulation are the wheel tire dynamics in conjunction with the ground force model and the brake torque model. Two displacements are important in the tire wheel system. The first is the angular displacement of the wheel which is utilized by the anti-skid system to provide the basis of control.



The second displacement is the movement of the footprint region of the tire. The footprint displacement is a paramount influence in the development of the friction force between the tire and the ground.

The ground force is developed using a composite model in which tire elastic properties predominate under limited slip conditions. As slip increases the ground force becomes a function primarily of the thermodynamics properties of the tire.

An extensive effort has also been made to reproduce the effects of a wet or contaminated runway in the wheel and tire/ground force portion of the simulation. The effects of vehicle velocity on the friction coefficient, the tire footprint center of pressure shift, and the water wedge are used.

Although the actual brake is used to determine the pressure volume characteristics, the brake does not serve as a torque producing element in the simulator. The brake torque pressure, temperature, speed relationships, retractor spring deadband, and frequency characteristics are included in the analog simulation.

The simulator also provides facilities for comprehensive evaluation of individual components. The hydraulic mockup provides the ability to test the hydraulic components in an idealized condition or under normal operation conditions.

Photographs of the Buffalo brake control simulator are shown in Figures 3A thru 6A. Table 1 (Figure 7A) is a list of parameters used in the Buffalo braking system simulator.



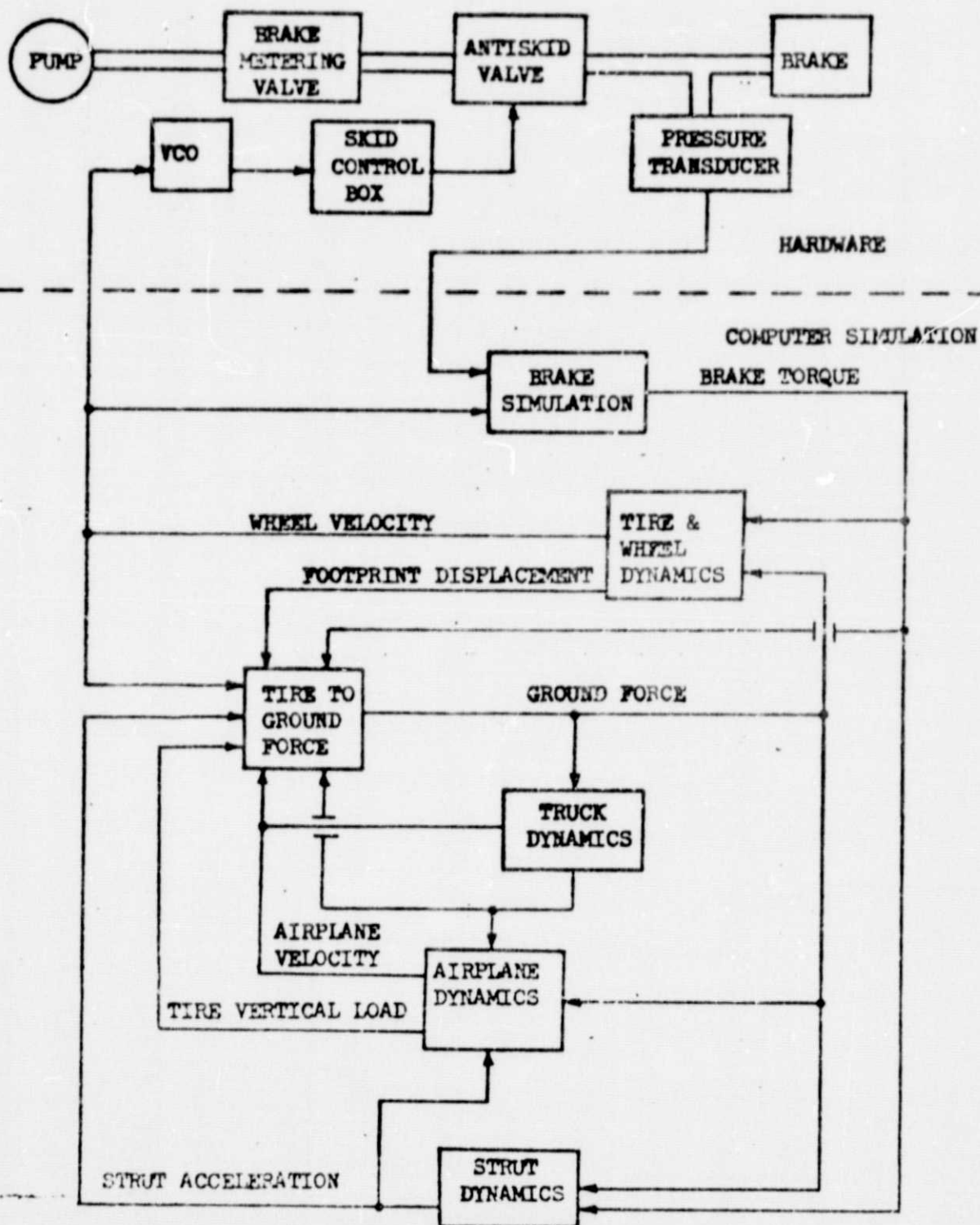
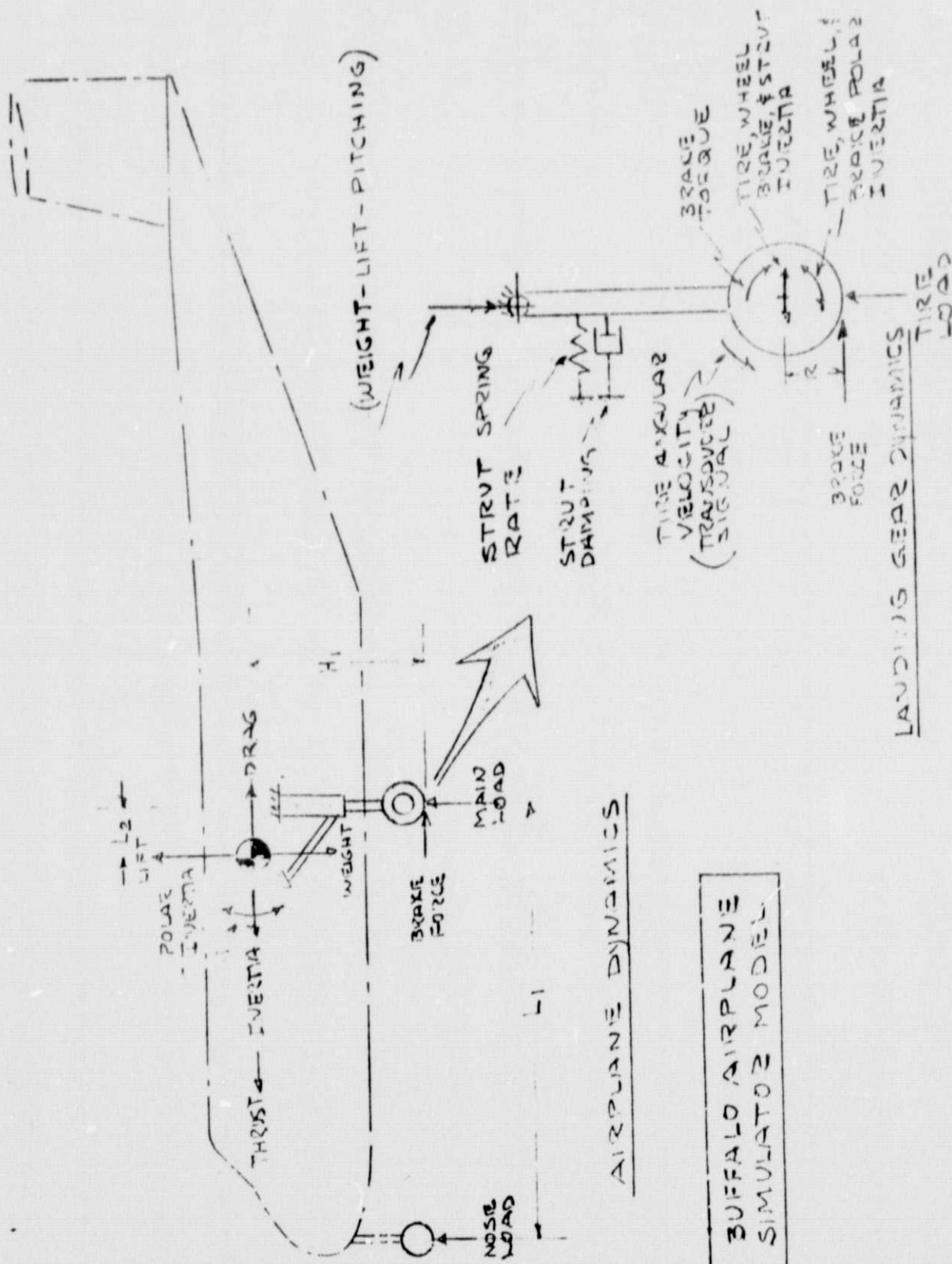
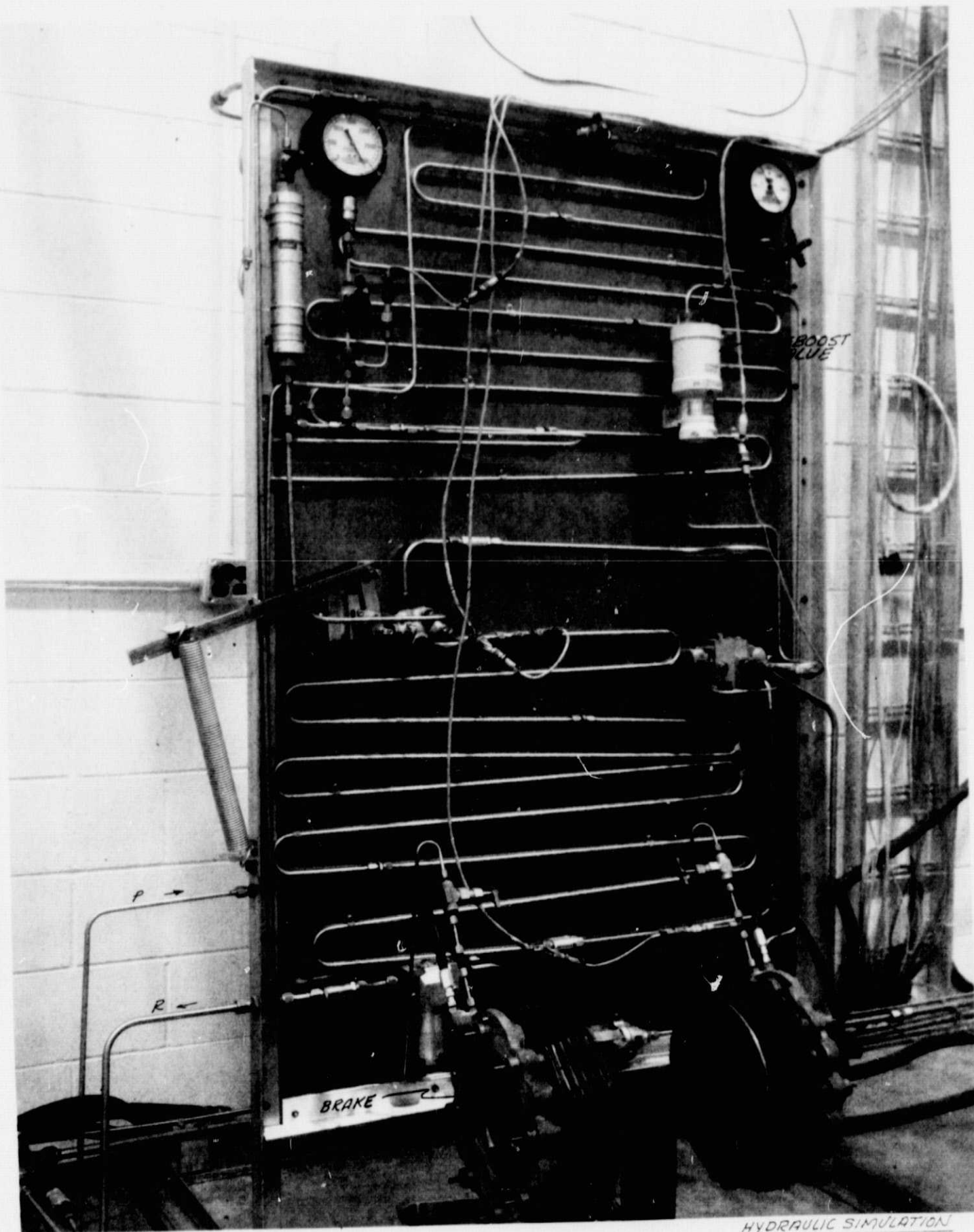


FIGURE 1A. SIMULATOR BLOCK DIAGRAM



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HYDRAULIC SIMULATION
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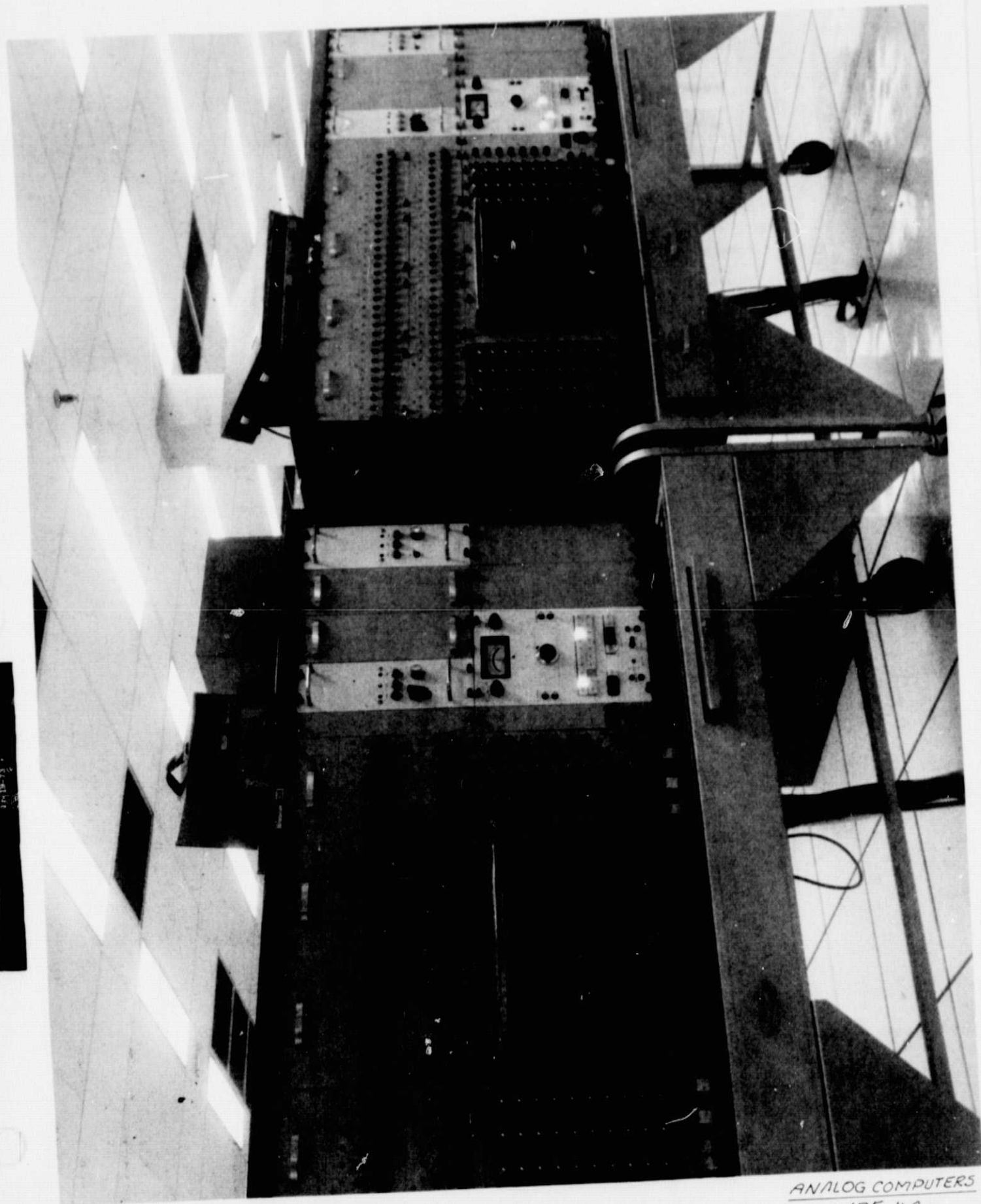
HYDRAULIC SIMULATION

FIGURE 3A

DC-41896

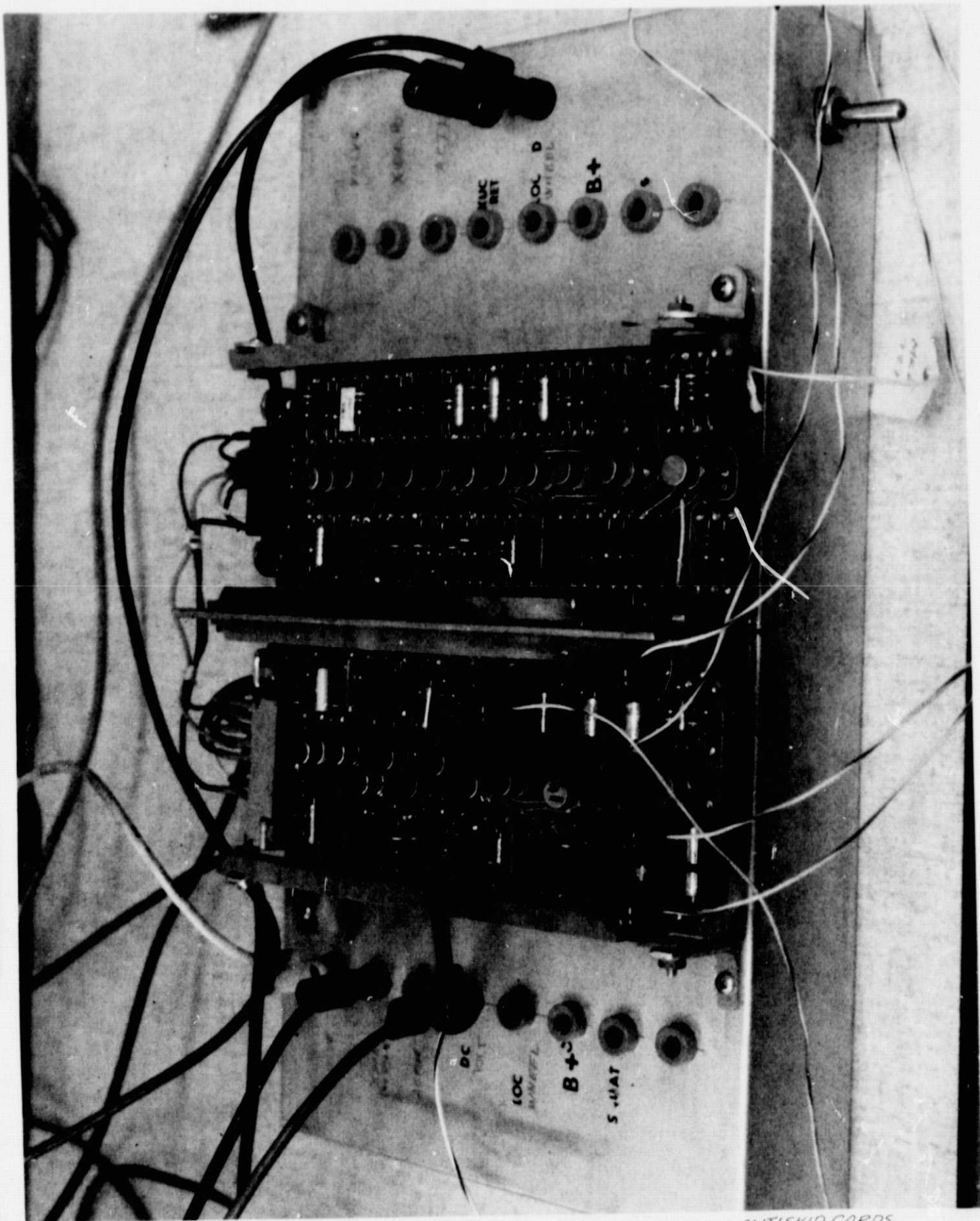
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30-28765
BUFFALO AIRPLANE BRASS AND ARTISER
SIMULATOR



ANALOG COMPUTERS
FIGURE 4A D6-41896
Page 34

347-257-1
BUFFALO AIRPLANE IMAGE AND ANTISKID
SIMULATION
11-18-73

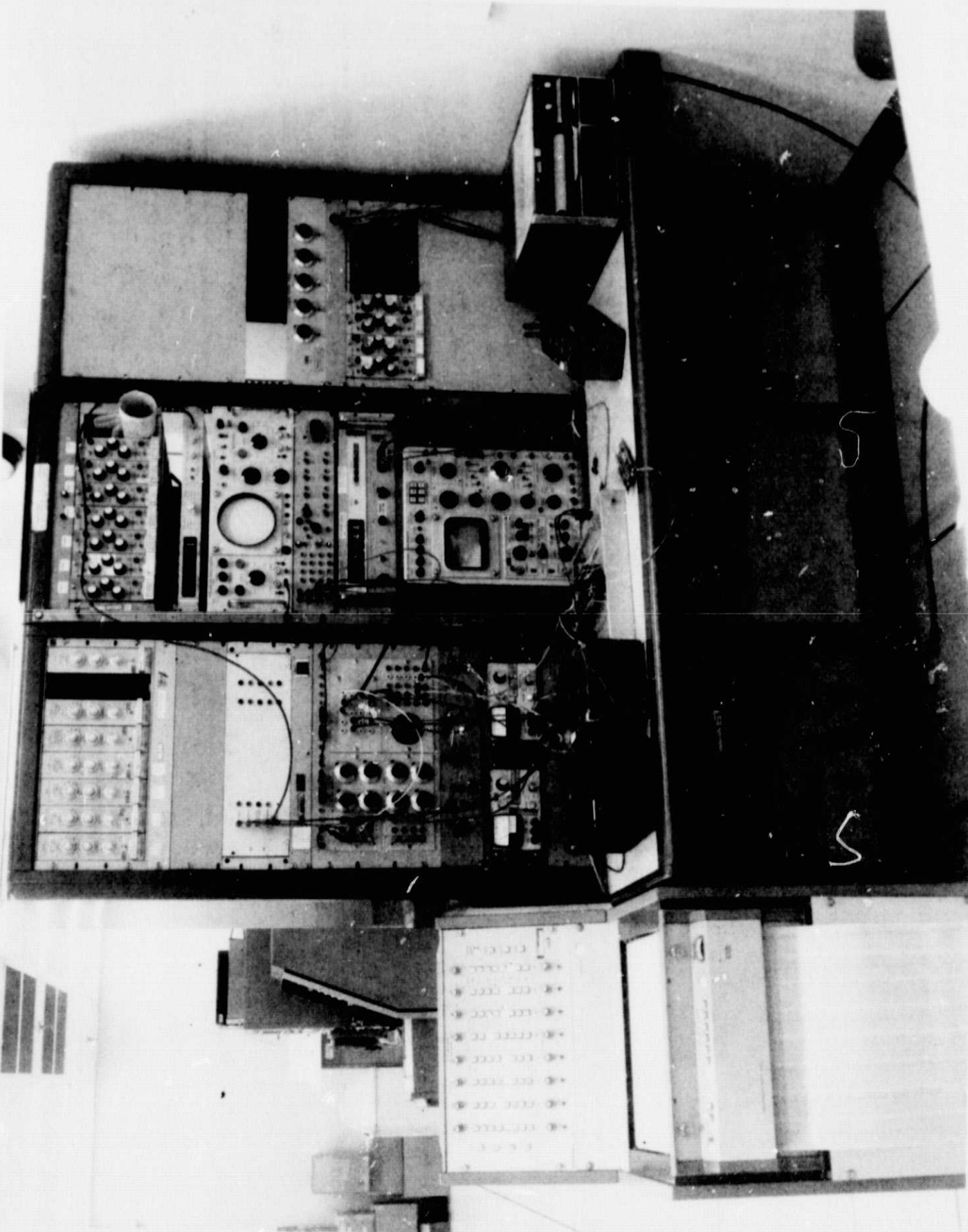


ANTISKID CARDS
FIGURE 5A

34725783

BUFFALO AIRPLANE IMAGE AND ANTISEEP
SIMULATION

11-19-72



INSTRUMENTATION
FIGURE 6A

TABLE I
BUFFALO PARAMETERS

<u>PARAMETERS</u>	<u>SYMBOL</u>	<u>VALUE</u>	<u>UNITS</u>
<u>Airplane Parameters</u>			
Wing Area	A_w	865.	ft^2
Coefficient of Lift			
Spoilers Up	C_L	.750	-
Spoilers Down	C_{L_D}	.745	-
Coefficient of Drag			
Spoilers Up	C_D	.242	-
Spoilers Down	C_{D_D}	.242	-
Engine Idle Thrust	F_e	0.	lb
Height of CG Above Ground	H_B	8.0	ft
Mass Moment of Inertia of the Airplane about the CG in the Ditch Direction	I_{yy}	2.05×10^5	$ft-lb \text{ sec}^2$
Distance from Nose Gear to CG	L_A	24.28	ft
Distance from Main Gear to CG	L_B	3.55	ft
Number of Braked Wheels per Strut	N_B	2	-
Number of Braked Wheels per Airplane	N_{BA}	4	-
Number of Wheel on the Nose Strut	N_{BN}	2	-
Number of Main Gear Struts	N_s	2	-
Air Density		.00238	$\frac{lb - sec^2}{ft^4}$
Airplane Landing Weight	W_A	40000.	lb
Brakes on Velocity	V_I	89.46	ft/sec
Stop Velocity	V_{stop}	12.0	ft/sec
<u>Brake Parameters</u>			
Specific Heat of the Brake Heat Sink	C_{pb}	80.9	$\frac{ft-lb}{lb - F}$
Heat Sink Weight	M_B	58.0	lb

FIGURE 7A

TABLE I
BUFFALO PARAMETERS (cont'd)

<u>PARAMETERS</u>	<u>SYMBOL</u>	<u>VALUE</u>	<u>UNITS</u>
<u>Brake Parameters (cont'd)</u>			
Wheel Speed Ratio at Initial Torque peaking	ω_p	25.	%
Brake Contact Pressure	P_c	120.	psi
Brake Torque Gain	T_{BG}	5.66	$\frac{\text{ft-lb}}{\text{psi}}$
Peak Brake Torque	T_{BP}	8136.	ft-lb
Brake Temp. at Initial Fade	O_{BB}	3000.	°F
Torque Response Break Point	W_N	20.0	Hz
Torque Response Damping Ratio	ζ	.5	-
<u>Tire Parameters (32 x 11.5 - 15)</u>			
Mass Moment of Inertia about the Axle	I_w	2.07	ft-lb-sec ²
Outside Tire Radius	R	1.34	ft
Torque Radius	R_T	1.13	ft
Rolling Radius	RR	1.27	ft
Inflation Pressure	P_i	90.	psi
<u>Strut Parameters</u>			
Torsional Damping Coefficient	C_T	178.	ft-lb-sec
Fore & Aft Damping Coefficient	C_S	32.0	$\frac{\text{lb-sec}}{\text{ft}}$
Vertical Damping Coefficient Main Gear	C_o	15450.	$\frac{\text{lb-sec}}{\text{ft}}$
Nose Gear	C_{on}	9620.	$\frac{\text{lb-sec}}{\text{ft}}$
Mass Moment of Inertia of the Lower Strut and Non-Rotating Brake Parts	I_s	.8	ft-lb-sec ²
<u>Oleo Vertical Spring Rate</u>			
Main Gear	K_o	98,400.	lb/ft
Nose Gear	K_{on}	60,000.	lb/ft
Strut Fore & Aft Spring Rate	K_s	50,500.	lb/ft
Effective Strut Mass	M_s	12.8	$\frac{\text{lb-sec}^2}{\text{ft}}$
Effective Strut Length	L	9.3	ft

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APPENDIX B - BRAKE AND ANTI-SKID SYSTEM FUNCTIONAL TEST

I SYSTEM TO BE TESTED

Brake System

II REFERENCES

- (1) 65-83434 and 65-83551 Sheet 6
- (2) 65-83552 Modified C-8A Anti-Skid System Electrical System Mod.
- (3) ADCN #11 of Drawing 65-83008

III GENERAL INFORMATION

- (1) The purpose of this test is to operationally test the brake and anti-skid system.
- (2) Flushing, bleeding, and filling of the hydraulic system and control system rigging shall have been accomplished prior to performing this test.
- (3) Electrical continuity shall have been previously established prior to commencing this test. It shall be assumed that electrical power is available and the applicable power busses are energized.
- (4) No line hammer or chatter of the brake valve shall occur during any portion of the test.

IV TEST EQUIPMENT

- (1) Variable volume test bench using MIL-H-5606 hydraulic fluid capable of delivering approximately 10 gpm at 3000 psig and equipped with suitable fittings for connection to the airplane. Test bench filters shall be capable of oil filtration to 5 micron nominal and 15 micron absolute. Bench pressure shall be adjustable from 0 - 3300 psig.*

*An optional method is to use airplane hydraulic power.



- 212-247
- (2) Airplane jacks.
 - (3) 0 - 2000 psi range gauges for MIL-H-5606 hydraulic fluid.
 - (4) Two hand held air drill motors in the 50 to 2000 rpm range each with a 1/4 inch rubber tube on a 1/4 inch arbor for rotating the anti-skid wheel detectors.
 - (5) 115V, 3 Phase, 400 cycle electrical power.

V. BRAKE OPERATIONS

- (1) Install a 0 - 2000 psi range gauge downstream of each brake deboost valve.
- (2) Close the anti-skid test circuit breakers. Retain the main gear anti-skid switches in the OFF position.
- (3) Gradually depress the Captain's or First Officer's brake pedals. Evidenced by a pressure indication on the test gauges at each brake.
- (4) Release brakes. Check each brake assembly for release by observing the brake stack. The brake pressure shall be 45 psi or less.
- (5) Pressurize System A to 3300 ± 100 psi. Apply and hold full brake pressure for five (5) minutes. There shall be no evidence of external leakage.
- (6) Pressurize hydraulic system.
 - (a) Attempt to set parking brake by depressing left brake pedal only. The parking brake shall not engage.
 - (b) Attempt to set parking brake by depressing right brake pedal only. The parking brake shall not engage.



- (c) Depress both pedals and set the parking brake. The anti-skid system must be OFF. Depressurize the hydraulic system leaving brake system pressurized with the accumulator. Record the brake pressure at each brake.

Brake Assy No. 1 _____ No. 2 _____

No. 3 _____ No. 4 _____

- (7) Release the parking brake. All brakes shall release completely.

- (8) Repressurize the hydraulic system and set the parking brake.

Depressurize the hydraulic system leaving brake system pressurized with the accumulator. Measure and record the position of the main gear lockout deboost valve indicators with respect to a convenient fixed reference on deboost valve housing. At the end of 8 hour period, the pressure at the brake shall not be less than 500 psig, and each deboost valve indicator shall not have traveled more than .10 inches towards the short red band end.

Brake Assy Pressure No. 1 _____ No. 2 _____ No. 3 _____ No. 4 _____

Initial Deboost Valve Indicator Post. No. 1 _____ No. 2 _____ No. 3 _____ No. 4 _____

Final Deboost Valve Indicator Post. No. 1 _____ No. 2 _____ No. 3 _____ No. 4 _____



VI ANTI-SKID SYSTEM

- (1) With the airplane on the ground and oleos compressed normally, brakes bled, deboost valves correctly serviced, and parking brake released:
 - (a) Close the outboard anti-skid, inboard anti-skid and test circuit breakers.
 - (b) Place the main gear anti-skid switch in the ON position.
- (2) Chock wheels, release parking brakes, and remove hub caps and wheel transducer couplings. Note: Do not disconnect electrical connectors.
- (3) Depress brake pedals completely to apply all brakes. Keep brake pedals depressed for remainder of test unless otherwise stated. All main brake release indicators shall be OFF.
- (4) Place the anti-skid test switch in the OUTBD position, thus simulating rotation of all outboard wheels.
 - (a) The main inboard brakes shall release (as observed by ground personnel) and the inboard brake release indicators shall read "REL".
 - (b) The main outboard wheel brakes shall be applied and the outboard brake release indicators shall be OFF. Outboard may momentarily show "REL" when test switch is returned to normal. If the outboard indicators momentarily shows "REL", its duration shall be less than 0.5 second.



- (5) Place the anti-skid test switch in the INBD position thus simulating rotation of all inboard wheels.
- (a) The main outboard brakes shall release (as observed by ground personnel) and the outboard brake release indicators shall read "REL".
 - (b) The main inboard brakes shall be applied and the inboard brake release indicators shall be OFF. Inboard indicator may momentarily show "REL" when test switch is returned to normal. If the inboard indicator momentarily shows "REL" its duration shall be less than 0.5 second.
- (6) Using an air motor, rotate the transducer on one main wheel at a time at a steady speed between 120 and 1200 rpm. Observe the brake stack on each wheel and the control cabin indicators.
- (a) The brakes shall be released and indicators shall read "REL" as specified in the table below. All other brakes shall be applied and all other indicators shall be off.

<u>Detector Rotated</u>	<u>Brakes Released</u>	<u>Indicators at "REL"</u>
Left Outboard	No. 4	R. Outboard
Left Inboard	No. 3	R. Inboard
Right Inboard	No. 2	L. Inboard
Right Outboard	No. 1	L. Outboard

- (b) Abruptly stop the transducers. Its corresponding brake, shall momentarily release. The corresponding brakes indicator may momentarily show "REL". All released main gear brakes shall then reapply and their indicators shall go off.



- (7) Simulate an airplane in air condition as follows:
- (a) Press and hold down the air sensing and ground sensing switches on the landing gear. All brake release indicators shall read "REL" and all brakes shall release.
- (8) With airborne condition still simulated, place the anti-skid test switch to the OUTBD position.
- (a) The main inboard brakes shall be released and the inboard brake release indicators shall read "REL".
 - (b) The outboard wheel brakes shall be applied and their brake release indicators shall be off.
- (9) With airborne condition still simulated, place the anti-skid test to the INBD position.
- (a) The main outboard brakes shall release and the outboard brake release indicators shall read "REL".
 - (b) The main inboard wheel brakes shall be applied and the brake release indicators shall be OFF.



APPENDIX CFAILURE ANALYSIS - C-8A BUFFALO AIRPLANE
BRAKE AND ANTI-SKID SYSTEMTABLE OF CONTENTS

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I. INTRODUCTION

A. Scope

This is a detailed analysis of single failures of the C-8A Buffalo brake and anti-skid systems and their effects on airplane braking. Electrical, mechanical and hydraulic failures are considered. After a brief description of the systems, single failures are defined and analyzed for effect and corrective action.

B. Summary

The analysis shows that a high degree of safety was designed into the braking system.

Any failure in the braking system can be corrected by pilot action to assure sufficient braking capability and maneuverability during the landing roll. The majority of single failures do not require resorting to the pneumatic brakes. The discussion of a malfunction in this analysis does not suggest that such a failure is expected, and no effort was made to set up any order of probability for such a malfunction.

II. ANTI-SKID SYSTEM FAILURE ANALYSIS

A. Approach - Anti-Skid System

The analysis will be conducted in the following manner:

1. Consideration will be given to erroneous inputs to the anti-skid control box (due to single failures in the airplane wiring) and their effects on airplane braking.
2. A detailed failure analysis will be made of each component on the main wheel circuit card.



B. Design Objectives

The anti-skid system is designed such that:

1. No single electrical failure can cause loss of braking to more than half the wheels.
2. No single electrical failure can cause loss of manual braking to only one side of the airplane.

Design objective number 1 is obtained by having inboard and outboard main wheels controlled by completely independent electrical circuits.

Objective number 2 is accomplished by having individual wheel control; therefore, a single failure can cause loss of braking to only one wheel.

C. System Components

The anti-skid system consists of four elements:

1. An electromagnetic wheel speed transducer.
2. A transistorized anti-skid control box.
3. An electro-hydraulic anti-skid control valve.
4. A radio frequency interference filter on the control shield transducer input.

D. System Components Operation

1. Transducer

The wheel speed transducer is an axle mounted variable reluctance unit. The signal frequency is directly proportional to wheel speed. It consists of a rotor with 50 salient projections inside a stator with 50 projections. When the rotor and stator projections are directly opposed the air gap is small and a flux path of high magnetic reluctance is obtained in the position of

greatest air gap. This unit has only one moving part, the rotor, and has no commutator or slip rings. A DC voltage source is connected to the stator winding through a dropping resistor providing excitation for the transducer magnetic circuit. Rotation of the transducer shaft causes changes in the flux linking the stator winding and produces a small AC voltage which is fed to the first stage of a control circuit for one wheel.

The transducer is of simple, rugged construction conducive to long trouble-free service.

2. Control Box

a. General

The anti-skid control box contains four printed circuit cards, one for the control of each of the main brake anti-skid valves; each wheel driven transducer generates a wheel speed signal voltage which is fed to the corresponding printed circuit card. A sudden drop in the speed of a main wheel is sensed by the circuit as a skid and feeds voltage to the corresponding main wheel anti-skid valve to remove brake pressure and allow the wheel to recover speed.

The anti-skid control cards consist of solid state components enclosed in a rack mounted package. All circuit components are conservatively designed to provide a highly reliable package.



b. Rate Control With Feedback Modification - Main Wheel

The first stage of the control circuit is common to both the rate and locked wheel control. The output of the second stage of the rate sensing circuit is a DC voltage of "velocity" signal with a magnitude inversely proportional to wheel speed. If there is a sudden increase in the velocity signal due to a sudden reduction in wheel speed (a skid), a control voltage is obtained through the rate amplifier and valve driver circuits. This control voltage is applied to the anti-skid control valve to remove hydraulic brake pressure.

Wheel decelerations below a certain "rate threshold" are within the airplane's deceleration capability and produce no correction signal. Wheel decelerations above this threshold produce correction signals but only after the wheel has experienced a fixed velocity change. Spurious signals due to gear walking are therefore attenuated.

Shortly after a wheel ceases to decelerate, the correction signal is reduced to a value which depends on how long the wheel has been receiving the correction signal. Thus, the circuit integrates the strength and duration of the corrective signals building up a corrective bias which remains after the wheel ceases to decelerate, but which decays exponentially with time. This feature, known as pressure bias modulation (PBM) allows the wheel to adapt to the runway conditions by adjusting the brake reapplication pressure to a tolerable level.

If the runway coefficient of friction is low the PBM will build up the valve voltage to a relatively high level and provide low brake pressure.



c. Locked Wheel Control - Main Wheel

Locked wheel sensing is included as a precaution against failure of the rate circuit to properly regulate wheel speed. Each main wheel has a separate locked wheel circuit which provides a DC reference level, approximately 16 volts when the wheel speed is above approximately 25 knots. Below 25 knots the reference level diminishes linearly to zero, reaching zero at approximately 7 knots. The inboard and outboard reference levels are separately paired by a connection called the "memory". A separate logic circuit for each wheel compares its own wheel speed reference level with that of its paired wheel via the "memory" connection. When the skidding wheel drops to below approximately 10 knots the logic transistor (Q5) draws current from its valve driver, which produces a full valve voltage and releases the brake pressure to allow recovery of the skidding wheel.

The locked wheel circuit becomes inoperative below approximately 14-17 knots since the reference levels become insufficient to drive the logic transistor (Q5) into conduction. This prevents the locked wheel circuit from producing unwanted brake releases during taxi and parking maneuvers.

The inboard and outboard memory circuits are brought out of the control box so they can be commoned during the test function. A capacitor is connected from each memory circuit to ground to eliminate transient disturbances from the memory circuits.

d. Test Circuit (Refer to Figure 1)

The purpose of the test circuit is to advise the flight crew as to the condition of the system electrical circuitry prior to takeoff or landing. Correct response of the anti-skid release indicators to test switch operation assures continuity of the wheel transducer and proper operation of the locked wheel control and valve driving circuits. The test is obtained by applying a 400 cycle signal to simulate airplane wheel rotation.

Correct response to the operation of the test switch is as follows:

On the ground with power supplied to the system, and the airplane stationary, all four main wheel release indicators show blank. Movement of the test switch to the "outboard" position causes the two inboard release indicators to show REL. Movement of the test switch to the "inboard" position causes the two outboard release indicators to show REL.

With the airplane in flight and the anti-skid system on, the four main wheel release indicators show REL. Operation of the test switch produces the same end result as for the ground test, the only difference being the initial condition of the release indicators.

e. Inflight Arming (Touchdown Protection)

Prior to touchdown, both squat switches are closed, thereby applying 28 volts DC to the locked wheel control circuits to provide release of braking prior to touchdown. Wheel spin-up at touchdown produces a signal which is sufficient to overcome the safety relay input and allow brake application even if one or both squat switches fail to open.



3. Anti-Skid Control Valve

The anti-skid control valve is an electro-hydraulic servo valve which converts small electrical signals into strong hydraulic outputs. The input to the servo valve is a low level DC voltage from the control shield which has a maximum value of about 10 volts. Pressure from the pilot's brake metering valve supplies the anti-skid valve which in turn may decrease pressure to the brakes in proportion to the strength of the signal received from the control shield. In the event of a strong skid control signal the valve is capable of reducing brake pressure to practically zero, but in no case can it apply more pressure than is being supplied through the pilot's metering valve. The valve is spring biased in the "pressure to brake" position such that in the absence of an electrical signal from the control box it remains open and constitutes only a minor restriction between the metering and deboost valves.

Two units as just described are housed in a single body so they share common pressure and return lines, but operate independently. The return line shut-off solenoid is de-energized and blocks the return port when the anti-skid system is turned off. This preserves the effectiveness of the brake accumulator as a means of parking the airplane with all hydraulic power sources dormant.

4. RFI Filter

A radio frequency filter was added to the anti-skid system on airplanes with high frequency transmitters. This was necessary to prevent the high frequency signal from coupling into the wheel speed transducer wiring and causing the anti-skid controller to release the brakes. The filter is connected in series with the wheel speed transducer and blocks the interference signal from entering the anti-skid control box. The filter consists of one capacitor and one choke for each main wheel transducer input to the control shield.



E. Airplane Wiring

The airplane wiring schematic is given by Reference 1. Outboard and inboard wheel circuits have completely independent circuits for power supply, touchdown protection, and system test. The main gear anti-skid valve return line shut-off solenoids share a common voltage source.

Power for each set of inboard and outboard wheels is supplied from two separate 28 volt DC power busses through two circuit breakers. A pilot operated "on-off" switch is used to turn the anti-skid system on and off.

Test switches for "inboard" and "outboard" wheels apply a 400 cycle signal to the control box to simulate wheel rotation. During operation of the test switch both inboard and outboard main wheel locked wheel circuits are connected together to form a common memory and thus obtain a reference voltage to produce a locked wheel signal and operation of the release indicators.

1. The Buffalo airplane anti-skid is similar to that of the Boeing 727 except the Buffalo airplane wiring is simplified. For this reason, only the Buffalo airplane wiring will be analyzed. Refer to Reference 1 and Figure 1.

a. Loss of Outboard Wheel Circuit Breaker

Result: Loss of anti-skid protection for the outboard wheels. Manual braking will be retained on these wheels. The cockpit anti-skid test display will indicate this failure since the outboard indicators will not illuminate during test or prior to landing.

Action: Use the normal braking system except use light pedal force. Excessive pedal force can cause tire failure of the outboard tires.



b. **Loss of Inboard Wheel Circuit Breaker**

Result: Loss of anti-skid protection for all wheels because power is lost to both anti-skid valve module solenoid shut-off valves which prevents anti-skid pressure release. The cockpit anti-skid test display will indicate this failure since the inboard indicators will not illuminate during test or prior to touchdown. Normal manual braking is retained.

Action: Use the normal braking system except apply only light pedal force. Excessive pedal force can cause tire failure of all main landing gear tires.

c. **Loss of Solenoid Shut-Off Power to Only One Anti-Skid Valve Module**

Result: Possible tire failure to both tires on one side of the airplane if high pedal force is applied. A sustained cockpit display REL indication on both affected wheels will result. Test prior to landing will not detect this failure. Observation by ground personnel of failure of both brakes to release during the "inboard-outboard" test will indicate this failure.

Action: Quick release of pedal force upon observing sustained REL indicators will prevent tire failure. This to be followed by use of light pedal force. In the event of tire failure of both tires on the same gear, maintain lateral control with opposite brakes, nose wheel steering and rudder.



d. Loss of the 400 H₂ 26 VAC Circuit Breaker

Result: Cockpit display REL indicators will indicate failure. With the airplane in the air, indicators will not extinguish during the "inboard-outboard" test. With the airplane on the ground, the indicators will not illuminate during the "inboard-outboard" test.

Action: Use normal braking system except apply light pedal force.

e. Squat Switch Failed Open

Result: Loss of touchdown protection on the associated paired wheels. Cockpit display indicators will indicate the failure by not illuminating REL prior to landing. Brake application prior to landing could result in failure of one tire on each side of the airplane.

Action: Use normal braking system except apply light pedal force.

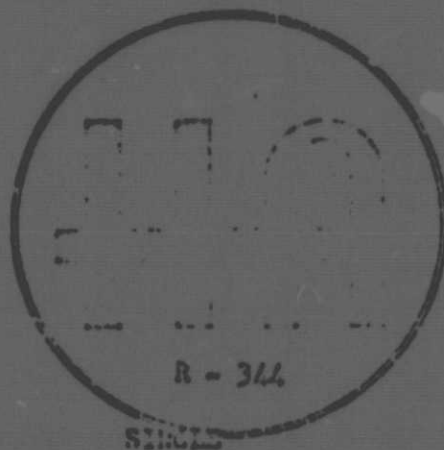
f. Squat Switch Failed Closed

Result: Loss of braking on two symmetrical brakes below approximately 15 knots. Other two symmetrical brakes are unaffected. Sustained illumination of REL indicators at low speed indicate this failure.

Action: Turn off anti-skid system and use normal taxi braking technique.



Revised 10/16/62
Revised 3/22/63
Revised 4/20/64
TO "B" CHANGE



FAILURE ANALYSIS REPORT ON
THE HYDROL CONTROL SHIELD MARK II FOR
THE BOEING 727 AIRPLANE

Prepared by: C. Poluka

Approved by: S. Licens

Date: 10-12-62

SECTION NO. 1 - MAIN WHEEL CONTROL CIRCUIT

(Refer to schematic 42-527122)

Note: Effect shown is on the associated wheel only unless otherwise stated.

<u>SYMBOL</u>	<u>COMPONENT</u>	<u>CONDITION OF FAILURE</u>	<u>EFFECT ON SYSTEM</u>	<u>EFFECT ON BRAKING</u>
C1	Capacitor, Solid Tantalum	Open	Control circuit inoperative on associated wheel	Loss of skid and locked wheel control to associated wheel
C1	Capacitor, Solid Tantalum	Shorted	Control circuit inoperative on associated wheel	Loss of skid and locked wheel control to associated wheel
C2	Capacitor, Mylar	Open	Control circuit inoperative on associated wheel	Loss of skid and locked wheel control to associated wheel
C2	Capacitor, Mylar	Shorted	Continuous velocity signal	Ineffective skid relief. Opposite wheel will lose braking below locked wheel level. No locked wheel protection.
C3	Capacitor, Solid Tantalum	Open	Pulsating low level skids at low RPM	Reduced braking efficiency at low RPM
C3	Capacitor, Solid Tantalum	Shorted	Control circuit inoperative on associated wheel	Loss of skid and locked wheel control to associated wheel
C4	Capacitor, Solid Tantalum	Open	Slightly increased skid sensitivity pulsating output at low RPM	Slightly reduced braking efficiency at low RPM
C4	Capacitor, Solid Tantalum	Shorted	Control circuit inoperative on associated wheel	Loss of skid and locked wheel control to associated wheel
C5	Capacitor, Solid Tantalum	Open	Pulsations on locked wheel output at the edge of locked wheel control	No loss of braking efficiency
C5	Capacitor, Solid Tantalum	Shorted	Loss of locked wheel signal	No locked wheel control available. Anti-skid control available.
C7	Capacitor, Solid Tantalum	Open	No skid signal to rate circuit	Loss of skid control to associated wheel, locked wheel control only.

<u>STOCK</u>	<u>COMPONENT</u>	<u>CONDITION OF FAILURE</u>	<u>EFFECT ON SYSTEM</u>	<u>EFFECT ON BRAKING</u>
C-7	Capacitor, Solid Tantalum	Shorted	continuous skid level output	Loss of brakes
C-9	Capacitor, Solid Tantalum	Open	Alter ation of response parameters	Slight loss of braking efficiency
C-9	Capacitor, Solid Tantalum	Shorted	Loss of rate signal and locked wheel signal	Loss of skid and locked wheel control
C-10	Capacitor, Solid Tantalum	Open	Alter ation in system response parameters	Slight loss of braking efficiency
C-10	Capacitor, Solid Tantalum	Shorted	Loss of rate signal	Loss of skid control
C-11	Capacitor, Solid Tantalum	Open	Loss of PFM (Pressure bias modulation)	Reduced braking efficiency due to excessive cycling.
C-11	Capacitor, Solid Tantalum	Shorted	Loss of PFM	Reduced braking efficiency due to excessive cycling
C-12	Capacitor, Solid Tantalum	Open	Dependent upon 28 volt bus noise; increased skid sensitivity	Slight loss of braking efficiency for high performance landings
C-13	Capacitor, Solid Tantalum	Shorted	Control system inoperative on associated wheel	Loss of skid and locked wheel control to associated wheel
C-14	Capacitor, Metalized Mylar	Open	Possible high frequency oscillation in regulator	Negligible
C-14	Capacitor, Metalized Mylar	Shorted	Partial loss of regulation and increase in B ⁺	Increased skid sensitivity and change of locked wheel actuation level
C-15	Solid Tantalum	Open	Power on valve transient	Momentary loss of braking for 2-5 seconds after power on
C-15	Capacitor, Solid Tantalum	Shorted	Rate amplifier biased off	Loss of skid control to associated wheel. Locked wheel control only
CR1	Diode, Zener	Open	Loss of precise regulation	Slightly increased skid sensitivity
CR1	Diode, Zener	Shorted	Control circuit inoperative	Loss of skid and locked wheel protection

<u>SYMBOL</u>	<u>COMPONENT</u>	<u>CONDITION OF FAILURE</u>	<u>EFFECT ON SYSTEM</u>	<u>EFFECT ON BRAKING</u>
CR2	Diode Zener	Open	Change in velocity calibration and temperature compensation	Reduced efficiency at high speeds and high performance landings.
CR2	Diode Zener	Shorted	Loss of velocity signal	Loss of brakes to associated wheel, above locked wheel level.
CR3	Diode Silicon	Open	None	None
CR3	Diode Silicon	Shorted	Control circuit inoperative	Loss of braking
CR4	Diode Silicon	Open	Loss of locked wheel velocity-logic relationship	Momentary loss of brakes near locked wheel level
CR4	Diode Silicon	Shorted	Loss of isolation between rate and locked wheel	Loss of brakes at low RPM and stop
CR5	Diode Silicon	Open	Loss of locked wheel	Locked wheel protection
CR5	Diode Silicon	Shorted	Support to associated wheel	Unavailable for associated wheel
CR6	Diode Silicon	Open	Saturation of rate amplifier	Loss of braking
CR6	Diode Silicon	Shorted	Decreased skid threshold	Braking efficiency decreased due to reduced skid threshold.
CR7	Diode Zener	Open	No release indication	None
CR7	Diode Zener	Shorted	Release indication on skid signals	None
CR8	Diode Silicon	Open	Loss of locked wheel signal	Locked wheel protection is unavailable
CR8	Diode Silicon	Shorted	Small locked wheel drive at high temperatures	Small standing voltage on valve at high temperature
CR9	Diode Germanium	Open	Increased PPM charge time	Reduced efficiency due to more rapid cycling
CR9	Diode Germanium	Shorted	PPM signal shorted out	Reduced efficiency due to more rapid cycling

<u>SYMBOL</u>	<u>COMPONENT</u>	<u>CONDITION OF FAILURE</u>	<u>EFFECT ON SYSTEM</u>	<u>EFFECT ON BRAKING</u>
CR10	Diode Zener	Open	Loss of velocity signal	Loss of brakes above locked wheel level. No locked wheel protection for opposite wheel.
CR10	Diode Zener	Shorted	Reduced velocity signal	Foot skid detection sensitivity and high locked wheel RPM level, loss of brakes between offset and normal locked wheel level
CR11	Diode Silicon	Open	Loss of clamped level on control signal	Loss of efficiency due to excessive pressure dump

<u>SYMOL</u>	<u>SYMBOL</u>	<u>CONDITION OF FAILURE</u>	<u>EFFECT ON SYSTEM</u>	<u>EFFECT ON BRAKING</u>
6K1	Diode Silicon	Shorted	Continuous rate signal	Loss of brakes due to continued control signal.
6K2	Diode Zener	Open	Loss of clamp level to control signal	Reduced efficiency due to excessive pressure dump of control valve
6K3	Diode Zener	Shorted	Rate signal shorted out. Increased loading of locked wheel signal	Ineffective skid control output and somewhat reduced locked wheel control
Q1	Transistor Silicon	Open	Loss of B+	Loss of skid and locked wheel control to associated wheel
Q2	Transistor Silicon	Shorted	Circuit B+ is a function of system voltage	Minor loss of efficiency on high performance and high slip landing conditions due to increased rate sensitivity and valve overdrive
Q2	Transistor Silicon	Open	Loss of velocity signal	Loss of brakes above locked wheel level. No locked wheel protection for opposite wheel.
Q2	Transistor Silicon	Shorted	Loss of velocity voltage	Loss of brakes above locked wheel level. No locked wheel protection for opposite wheel.
Q3	Transistor Silicon	Open	Loss of velocity signal	Loss of brakes above locked wheel level. No locked wheel protection for opposite wheel.
Q3	Transistor Silicon	Shorted	Full velocity signal	Loss of skid and ... wheel control to associated wheel. Brake release on opposite wheel below locked wheel level.
Q4	Transistor Silicon	Open	No wheel velocity to locked wheel comparison	Loss of brakes above locked wheel level. No locked wheel protection for opposite wheel.
Q4	Transistor Silicon	Shorted	Locked wheel signal shorted out	Loss of locked wheel control brake release on opposite wheel below locked wheel level.
Q5	Transistor Silicon	Open	No locked wheel signal to valve driver	Loss of locked wheel control to associated wheel - normal anti-skid control available
Q5	Transistor Silicon	Shorted	Simulates continuous rotation of opposite wheel	Release of brakes to associated wheel below locked wheel level.

HYDROL	COMPONENT	CONDITION OF FAILURE	EFFECT ON SYSTEM	EFFECT ON BRAKING
Q6	Transistor Silicon	Open	saturation of rate amplifier	loss of brakes to associated wheel
Q6	Transistor Silicon	Shorted	Removal of skid velocity component - alteration of skid threshold sensitivity	Moderate loss of efficiency due to decreased skid sensitivity
Q7	Transistor Silicon	Open	Loss of rate signal	Loss of skid control
Q7	Transistor Silicon	Shorted	Continuous rate signal	Loss of brakes
Q8	Transistor Silicon	Open	Loss of valve signal	Loss of skid and locked wheel control
Q8	Transistor Silicon	Shorted	Full valve drive	Loss of brakes
Q9	Transistor Silicon	Open	Loss of valve drive	Loss of skid and locked wheel control
Q9	Transistor Silicon	Shorted	Full valve drive	Loss of brakes
Q10	Transistor Silicon	Open	Loss of release indication	None
Q10	Transistor Silicon	Shorted	Continuous release indication	None
Q11	Transistor Silicon	Open	Loss of velocity signal to rate amplifier	Loss of skid control to associated wheel - locked wheel control available
Q11	Transistor Silicon	Shorted	Continuous velocity signal	Loss of brakes, above locked wheel level. No locked wheel protection for opposite wheel.
R1	Resistor Composition	Open	Loss of B+	Loss of skid and locked wheel control to associated wheel
R1	Resistor Composition	Shorted	None	None

<u>TEST</u>	<u>DEFECT</u>	<u>CONDITION OF FAULT</u>	<u>EFFECT ON SYSTEM</u>	<u>EFFECT ON BRAKING</u>
E2	Resistor Composition	Open	Loss of B+	Loss of skid and locked wheel control
E2	Resistor Composition	Shorted	Loss of regulation	Decreased efficiency on high performance landings due to increased skid sensitivity
E3	Resistor Composition	Open	No velocity signal	Loss of brakes above locked wheel level. No locked wheel protection for opposite wheel.
E3	Resistor Composition	Shorted	No system test signal to associated wheel	None
E4	Resistor Composition	Open	No velocity signal	Loss of brakes above locked wheel level. No locked wheel protection for opposite wheel.
E4	Resistor Composition	Shorted	velocity signal change	Somewhat reduced braking efficiency due to decreased skid sensitivity
E5	Resistor Composition	Open	No velocity signal	Loss of braking
E5	Resistor Composition	Shorted	No velocity signal	Loss of brakes above locked wheel level. No locked wheel protection for opposite wheel.
E6	Resistor Composition	Open	No system test signal	None
E6	Resistor Composition	Shorted	Degradation of G2 due to system test	Reduced skid and locked wheel effectiveness as G2 degrades
E7	Resistor Composition	Open	No velocity signal	Loss of brakes above locked wheel level. No locked wheel protection for opposite wheel.
E7	Resistor Composition	Shorted	Loss of velocity signal	Loss of brakes above locked wheel level. No locked wheel protection for opposite wheel.
E8	Resistor Composition	Open	No velocity signal	Loss of brakes above locked wheel level. No locked wheel protection for opposite wheel.
E8	Resistor Composition	Shorted	Velocity signal increased	Decrease in maximum performance landing capabilities due to decreased rate threshold
E9	Resistor Composition	Open	Change in velocity calibration together with erroneous velocity signal at high temperature	Increased skid sensitivity

<u>SYMBOL</u>	<u>COMPONENT</u>	<u>CONDITION OF FAILURE</u>	<u>EFFECT ON SYSTEM</u>	<u>EFFECT ON BRAKING</u>
R9	Resistor Composition	Shorted	No velocity signal	Loss of brakes above locked wheel level. No locked wheel protection for opposite wheel.
R10	Resistor Composition	Open	No velocity signal	Loss of brakes above locked wheel level. No locked wheel protection for opposite wheel.
R10	Resistor Composition	Shorted	Increased velocity signal	Reduced skid protection at high RPM. Decreased braking efficiency at lower RPM
R11	Resistor Composition	Open	No velocity signal to rate amplifier	Loss of skid control to associated wheel. Locked wheel threshold raised.
R11	Resistor Composition	Shorted	Increased ripple on velocity signal at low RPM	Slight buildup of valve signal at low RPM
R12	Resistor Composition	Open	Increased velocity signal	Reduced skid protection at high RPM; decreased braking efficiency at lower RPM.
R12	Resistor Composition	Shorted	No velocity signal to rate amplifier	Loss of skid control to associated wheel - locked wheel control only
R13	Resistor Composition	Open	Lower locked wheel threshold	None down to norm. Locked wheel level then temporary loss of brakes to opposite wheels
R13	Resistor Composition	Shorted	No velocity signal to locked wheel circuit	Loss of brakes above locked wheel level. No locked wheel protection for opposite wheel.
R14	Resistor Composition	Open	Level of velocity signal change	Reduced skid protection at high RPM; decreased braking efficiency at lower RPM.
R14	Resistor Composition	Shorted	No velocity signal to rate amplifier	Loss of skid control - Locked wheel control only

<u>SYMBOL</u>	<u>COMPONENT</u>	<u>CONDITION OF FAILURE</u>	<u>EFFECT ON SYSTEM</u>	<u>EFFECT ON BRAKING</u>
R15	Resistor Composition	Open	Change in locked wheel threshold	Temporary loss of braking over some taxi speed range
P15	Resistor Composition	Shorted	Loss of locked wheel protection	Loss of locked wheel protection
R16	Resistor Composition	Open	No internal locked wheel support	No locked wheel protection available

<u>TEST</u>	<u>COMPONENT</u>	<u>CONDITION OF FAILURE</u>	<u>EFFECT ON SYSTEM</u>	<u>EFFECT ON BRAKING</u>
R16	Resistor Composition	Shorted	Change in locked wheel loading	Will produce a brake release near the locked wheel level.
R17	Resistor Composition	Open	Loss of locked wheel drive	Loss of locked wheel protection
R17	Resistor Composition	Shorted	Locked wheel cut-off bias removed	Will produce brake release near the locked wheel level
R18	Resistor Composition	Open	Change of locked wheel calibration	Will produce brake release near the locked wheel level
R18	Resistor Composition	Shorted	Loss of locked wheel drive	Loss of locked wheel protection
R19	Resistor Composition	Open	Slight change in rate calibration	Minor loss in efficiency
R19	Resistor Composition	Shorted	Loss of rate signal	Loss of anti-skid control
R20	Resistor Composition	Open	Increased rate sensitivity	Decreased efficiency especially in high performance and high slip landings conditions
R20	Resistor Composition	Shorted	Severely decreased rate sensitivity	Reduced efficiencies due to excessive wheel speed departures
R21	Resistor Composition	Open	Loss of locked wheel drive	No locked wheel protection available
R21	Resistor Composition	Shorted	Increased locked wheel drive - change in locked wheel calibration	None
R22	Resistor Composition	Open	Increased rate sensitivity	Reduced efficiency in high performance landings
R22	Resistor Composition	Shorted	Continuous rate signal	Loss of brakes to associated wheel
R23	Resistor Composition	Open	Loss of rate signal	Loss of skid control
R23	Resistor Composition	Shorted	Alteration of transient response	Minor loss of efficiency

<u>SYMBOL</u>	<u>COMPONENT</u>	<u>CONDITION OF FAILURE</u>	<u>EFFECT ON SYSTEM</u>	<u>EFFECT ON BRAKING</u>
R24	Resistor Composition	Open	Loss of brake release from squat signal	No touchdown protection
R24	Resistor Composition	Shorted	Small increase in wheel velocity required to over-ride squat switch	None
R25	Resistor Composition	Open	Locked wheel drive possible near locked wheel level	Possible temporary loss of brakes near locked wheel level
R25	Resistor Composition	Shorted	Shift in locked wheel threshold	Possible temporary loss of brakes near locked wheel level
R26	Resistor Composition	Open	Loss of valve amplifier drive	Loss of skid and locked wheel control
R26	Resistor Composition	Shorted	Alternation of transient time response parameters	Minor loss in system efficiency
R27	Resistor Composition	Open	Valve driver bypassed	Ineffective skid and locked wheel control
R27	Resistor Composition	Shorted	Voltage limit on locked wheel signal raised	None
R28	Resistor Composition	Open	Loss of valve signal	No wheel protection
R28	Resistor Composition	Shorted	Increased valve drive	Minor efficiency loss
R29	Resistor Composition	Open	No pressure bias Modulation signal	Loss of braking effort due to the rapid cycling of the associated wheel
R29	Resistor Composition	Shorted	Increased pressure bias Modulation charging time	Loss of braking effort due to excessive pressure dump
R30	Resistor Composition	Open	No release indication	None
R30	Resistor Composition	Shorted	Reduction of maximum amplitude of locked wheel signal	None

<u>SYMBOL</u>	<u>COMPONENT</u>	<u>CONDITION OF FAILURE</u>	<u>EFFECT ON SYSTEM</u>	<u>EFFECT ON BRAKING</u>
R32	Resistor Composition	Open	Drop in indicator threshold	None
P32	Resistor Composition	Shorted	Loss of indicator drive	None
R33	Resistor Composition	Open	Loss of threshold modification	Minor efficiency loss on high slip runways

<u>TEST</u>	<u>CONDITION</u>	<u>CONDITION OF PARTS</u>	<u>EFFECT ON SYSTEM</u>	<u>EFFECT ON BRAKING</u>
R33	Resistor Composition	Shorted	Full control drive after 1st skid cycle	Loss of brakes to associated wheel.
R34	Resistor Composition	Open	Increased Pressure Bias Modulation bleed-off time	Loss of efficiency due to increased reapplication time
R34	Resistor Composition	Shorted	Rapid Pressure Bias Modulation signal bleed-off	Reduced efficiency due to increased cycling
R35	Resistor Composition	Open	No Pressure Bias Modulation signal	Loss of efficiency due to excessive cycling
R35	Resistor Composition	Shorted	Loss of additive signal to Pressure Bias Modulation signal	Minor loss of braking efficiency.
R36	Resistor Composition	Open	Rate amplifier saturated	Loss of brakes to associated wheel
R36	Resistor Composition	Shorted	Increased skid sensitivity	Loss of efficiency due to excessive rate sensitivity and threshold
R37	Resistor Composition	Open	Decreased rate sensitivity	Loss of efficiency due to increased rate threshold
R37	Resistor Composition	Shorted	Rate signal abridged	Poor skid control
R38	Resistor Composition	Open	No return for rate signals	Very poor skid control
R39	Resistor Composition	Shorted	Saturated velocity signal	Loss of brakes above locked wheel level. No locked wheel protection for associated wheel.
R39	Resistor Composition	Open	Loss of control signal	Loss of skid control to associated wheel. Locked wheel control only
R39	Resistor Composition	Shorted	Alteration of system response parameters	Minor loss in efficiency
R40	Resistor Composition	Open	Leakage of Q ² amplified	Some standing valve voltage at high temperature. Not a proportional loss in efficiency
R40	Resistor Composition	Shorted	Loss of rate and locked wheel signal	Loss of skid and locked wheel control to associated wheel
R41	Resistor Composition	Open	Standing drive to valve amplifier	Loss of brakes to associated wheel

<u>SYSTEM</u>	<u>COMPONENT</u>	<u>CONDITION OF FAILURE</u>	<u>EFFECT ON SYSTEM</u>	<u>EFFECT ON BRAKING</u>
R42	Resistor Composition	Shorted	Loss of rate signal	Loss of skid control to associated wheel
R42	Resistor Composition	Open	Loss of failure indication for open valve coil	None
R42	Resistor Composition	Shorted	Continuous overdrive to valve	Loss of brakes to associated wheel
R43	Resistor Composition	Open	Valve relief signal with power on transient	Temporary loss of braking after power on approximately 3 to 5 seconds.
R43	Resistor Composition	Shorted	Overheat on valve control signal plus power on transient	Slight loss in efficiency to normal braking - momentary loss of brakes approximately 2 to 3 seconds after power is applied

III. MANUAL BRAKE SYSTEM FAILURE ANALYSIS

A. Description of the Manual Brake System

The Buffalo brake system is hydraulically powered and controlled manually by brake metering valves which are connected to the pilot's brake pedals thru a linkage system. Both the pilot and copilot have a pair of brake pedals, and both pairs are interconnected by tie rods such that the brakes can be applied by either pilot or, by both pilots simultaneously.

All four main gear wheels (two on each landing gear) are fitted with heat sink type disk brakes. Each pair of brakes is hydraulically actuated through a brake metering valve. The left main gear and the right main gear brake metering valves can be operated simultaneously or individually to provide for differential braking.

Lockout deboost valves between the brake metering valves and brakes deboost the metered pressure to 38.3% and limit hydraulic fluid loss if leakage occurs on the brake side of the deboost valve. These valves incorporate an internal replenishing valve which is operated manually during ground maintenance only. In this way fluid can be transferred from the high pressure side to the brake side to make up for possible losses from leaks or bleeding. An indicator stem operated by the deboost valve piston indicates the amount of fluid on the brake side of the valve and shows whether servicing is necessary or not.

An existing brake accumulator in the main brake circuit supplies parking brake pressure after all airplane hydraulic systems are depressurized.

An anti-skid system of the modulating type minimizes wheel skidding and prevents locked wheel conditions on all wheels. Dual anti-skid valves allow individual wheel control for the four main gear wheels.



A leak in the main brake system upstream of the metering valve can result in the loss of hydraulic braking for all main brakes. The existing pneumatic brake system must be used in this case. The pneumatic system supplies pressure only to the main brakes from a compressed nitrogen bottle. The normal hydraulic and the pneumatic brake systems are separated by shuttle valves at the brakes. The emergency system has neither anti-skid nor locked wheel protection and no differential braking is possible.

B. Failure Analysis

For the purpose of this analysis malfunctions will be categorized as control system failures and hydraulic failures. A control system failure is defined as a failure that causes loss of control of the brake hydraulic system. A hydraulic failure is defined as a failure of a component in the brake hydraulic system itself.

1. Jammed Brake Metering Valve

a. Jammed in Brakes "Off" Position

Result: Loss of braking ability for one main gear. Application of operable brakes on the other main gear would cause asymmetric braking and airplane yawing.

Action: Use pneumatic brakes, or remaining hydraulic brakes. Rudder pedals and/or nose gear steering will counteract yaw moment due to asymmetric braking.

b. Jammed in Brakes "On" Position

Result: Brakes on one main gear cannot be released. The airplane yaws unless the braking forces on the other main gear balance the braking forces of the jammed brakes. Anti-skid protection remains effective.



Action: Balance airplane yawing with opposite brakes. If this action does not result in sufficient deceleration, overbalance and counteract overbalancing moment with nose gear steering and/or rudder.

2. Broken Control Linkage at the Metering Valve

Result: Loss of braking ability for one main gear. Application of operable brakes on the other main gear would cause asymmetric braking and airplane yawing.

Action: Use pneumatic brakes; or remaining hydraulic brakes. Rudder pedals and/or nose gear steering will counteract yaw moment due to asymmetric braking.

3. Broken Return Spring

Result: Pedal deflects slightly toward "brakes on" position and the feel force decreases, but brakes will not be applied automatically as a result of spring failure. After brake application, pedal will not fully return to neutral, but brakes will release.

Action: Use brakes normally.

4. Loss of "B" - Hydraulic System Pressure for any reason other than a leak in the brake system - refer to Figure 1.

Result: Loss of normal hydraulic brake system.

Action: Use pneumatic brake system.



5. Rupture or leak between brake metering valve and brake accumulator.

Result: Loss of main gear braking capability and loss of "B" hydraulic system.

Action: Use pneumatic brakes.

6. Rupture or leak somewhere between a brake metering valve and the deboost valves in the main brake system.

Result: Opening the metering valve will in time cause loss of "B" system fluid, and some main brake ineffectiveness depending on size of the leak.

Action: If "B" hydraulic system is lost use pneumatic brakes with nose gear steering and rudder for directional control.

7. Rupture or leak between deboost valve and main brake.

Result: Loss of pressure for the one main brake concerned and asymmetric braking for equal pedal deflections. The "B" system fluid loss is limited to the deboost valve volume.

Action: Correct yaw tendency by metering less pressure on unfailed side. Nose gear steering and rudder may also be used for directional control.

8. Rupture or leak of return line between metering valve and return line check valve.

Result: A quantity of fluid will be lost when the brakes are applied and released with anti-skid on. Braking performance will be unchanged.



Action: Use brakes normally. The pilot will not be aware of this leak. Gradual loss of reservoir fluid would be observed.

9. Loss of nitrogen precharge in brake system accumulator

Result: Airplane cannot be parked unattended with depressurized hydraulic systems.

Action: Chock wheels.



REFERENCES

Boeing Drawings

65-83552 Mod. C-8A Anti-Skid System Electrical System Mod.
65-83434 Hydraulic System Diagram - Modified C-8A
Sheets 1
and 2
65-83551 Brake Control System Installation - Buffalo Mod. C-8A
Sheet 6

Boeing Documents

D6-7317 Failure Analysis -727 Anti-Skid System
Pages 16-
27 Note: This is a failure analysis of the Mark II anti-skid
system prepared by Hydro-Aire and is applicable
to the C-8A Anti-Skid System.

Hydro Aire Drawing

42-527410 Schematic Diagram Printed Wiring Assembly Main Wheel
Hytrol Mk II Control Box